

**REMARKS**

Claims 1, 3-5, 8, 11, 13 and 15 stand rejected under 35 USC 103(a) as obvious over Maeda in view of Karkozov. In particular, the Examiner alleges that, while Maeda fails to disclose or suggest the recited aromatic amine compound having a benzoxazole structure, it would have been obvious to include Karkozov's APBO in Maeda's composition to arrive at the claimed invention (Action, page 2, line 15, and page 3, line 2). This rejection is respectfully traversed.

As explained below and in the responses filed on November 17, 2008 and February 23, 2009, the Examiner's rejection is based on a mistranslation and resulting misunderstanding of the Maeda reference. Specifically, claim 1 as amended recites a curable composition that, at ambient temperature, comprises a solid dispersoid including a benzoxazole amine compound dispersed in a liquid continuous phase comprising a compound with two or more epoxy groups. In other words, because the solid dispersoid comprises specific amine compound that is incompatible with the continuous phase comprising the epoxy compound, the resulting mixture is a one-component curable composition that exhibits excellent stability and ease of use (Specification, page 4, lines 5-9). Further, because the amine compound is dispersed as a dispersoid in the claimed invention, the amine compound and the epoxy compound come into contact gently during the curing process, the resulting cured product exhibiting excellent uniformity (Spec. pg. 4, lines 20-26).

Maeda discloses a curable composition comprising a polyisocyanate compound, a urethane prepolymer and a surface-coated amine compound that is "heat-cured under a low temperature condition (e.g. 60° to 100°C × 10 min.)" (Maeda, column 1, lines 53-54). Achieving both low-temperature curability and sufficient storage stability is a key concept to Maeda's invention (Maeda, column 1, lines 24-29). Maeda's surface-coated amine compound has its melting points around the curing temperature (usually 60° to 100°C) of Maeda's composition, and it comes into contact with other active ingredients by melting through the fine-particle coating when the mixture is heated to the curing temperature. Thus, to maintain low-temperature curability, the melting point temperature

of the amine is important. It would not have been obvious to modify Maeda by substituting Maeda's amine compounds, which react by melting at the curing temperature, with Karkozov's 5-amino-2-(n-amino phenyl)-benzoxzaole (APBO) that is introduced to Karkozov's epoxide resin at 140°C in an amount of 10-30 weight% as a hardener. This is because Karkozov's APBO has a melting point in the range of 228-232°C (Karkozov, English translation, page 3, line 14). In other words, if APBO were coated with fine-particles and added to the Maeda's composition, Maeda's composition would not cure at Maeda's curing temperature of 60° to 100°C. Thus, using Karkozov's APBO in Meada's composition would render Meada's invention unsatisfactory for its intended purpose. Thus, Maeda teaches against the substitution proposed by the Examiner, and this rejection should be withdrawn.

In response to applicants' argument that the combination of Maeda and Karkozov would render Maeda's invention unsatisfactory for its intended purpose, the Examiner stated that the melting point of Maeda's amine is not important because "it is not the melting of the solid amine that starts the curing reaction, but the surface coating on the amine (col. 1 lls. 50-60). The amine does not need to be melted in order for the composition to cure." (See Final Action dated December 23, 2008, p. 3, lls. 33-40).

As stated in the response filed on February 23, 2009, the Examiner misunderstood column 1, lines 50-60, of Maeda. That paragraph of Maeda is stating that the curing of the composition starts, not by the melting of the fine particle coatings, but by the loss of the base support for the fine particles caused by the melting of the amine. Maeda's fine particles for coating are comprised of inorganic or polymeric compounds and do not melt under the curing condition of 60° to 100°C x 100 min. The melting first takes place with the solid amine, causing the surface coating particles to lose their base support and to collapse.

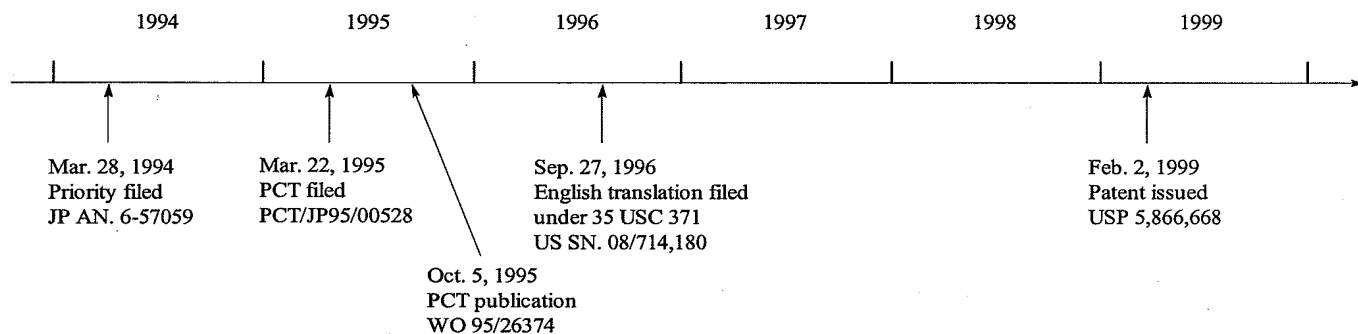
In the Advisory Action dated March 9, 2009, the Examiner has again defended her understanding of the Maeda reference as follows:

Applicant's argument that Maeda teaches curing the composition by melting the amine and not the fine particle coating is not persuasive. Maeda states, "the composition prepared according to such process can be heat-cured under a low temperature condition (e.g. 60° to 100°C.x1 0 min.) because the surface-coating of the solid amine is melted by heating to appear an active amino group on the surface thereof..." Therefore, the amine does not need to be melted in order for the composition to cure. It does not matter if a different amine is substituted into Maeda. This is especially true since clear motivation to do so is disclosed in Karkozov. The evidence provided (WO 95/26374) is not entered because applicant failed to provide a showing of good and sufficient reason why the evidence is necessary and was not earlier presented. Further, the rejection is based on the U.S. Patent, not the WIPO document or its other family members and it is not germane what the family members teach. Also, the translation provided is not certified.

Advisory Action dated March 9, 2009, page. 2. As stated above, the Examiner did not enter the previous evidence related to the WO version of Maeda. With the filing of the RCE herewith, this evidence should be entered into the record and considered by the Examiner. Further, as explained below, the Examiner's present understanding that the cited portion of the Maeda reference is referring to a separate surface coating is clearly incorrect.

#### **Mistranslation of WO 95/26374**

WO 95/26374 is not just a related application to the cited Maeda patent (USP 5,866,668). Appl. Serial No. 08/714,180 (which issued as US 5,866,668) is based on PCT/JP95/00528 under 35 U.S.C. § 371, and enjoys the priority benefit based on JP Appl. No. 6-057059. The English translation of WO 95/26374 was filed as the specification of Appl. Serial No. 08/714,180 (see 35 U.S.C. § 371(c)(2)). The time table for USP 5,866,668 is as follows.



Accordingly, the translation of WO 95/26374 is the original specification for USP 5,866,668. Since WO 95/26374 was filed in the original Japanese language, any differences between the specification of WO 95/26374 and the cited Maeda patent USP 5,866,668 are because of translation errors.

Attached is a declaration executed by Ms. Arimura, who is an experienced Japanese-English translator for many years.

As stated in the declaration, the passage “because the surface-coating of the solid amine is melted by heating” corresponds to the passage of WO 95/26374 , page 2, lines 4 and 5, “表面被覆された固形アミン化合物が加熱熔融によって、” and particularly the phrase “the surface-coating of the solid amine” corresponds to “表面被覆された固形アミン”.

However, the Japanese phrase “表面被覆された固形アミン” should not have been translated into the English phrase “the surface-coating of the solid amine” but correctly into an English phrase “the surface-coated solid amine”. Therefore, the disclosure of the cited passage of Maeda is technically incorrect due to the mistranslation.

In addition, the fact that the cited portion of the Maeda reference does not refer to “the surface-coating of the solid amine” but instead to the properties of “the surface-coated solid amine” would be obvious to one skilled in the art for the following additional reasons:

**Melting point of surface coating**

Claim 1 of Maeda provides the following list of materials as examples of the surface coating: **titanium oxide, calcium carbonate, clay, silica, zirconia, carbon, alumina, talc, polyvinyl chloride, polyacrylic acid resin, polystyrene and polyethylene** are recited in a limited way in claim 1. The melting points (or glass transition temperature: Tg) of these materials are shown in the following table:

Material	Melting point (°C)	reference
titanium oxide	>350°C	Aldrich Catalog 2000-2001
calcium carbonate	~800°C	Aldrich Catalog 2000-2001
clay <sup>1)</sup>	-	Wikipedia <a href="http://en.wikipedia.org/wiki/Clay">http://en.wikipedia.org/wiki/Clay</a>
silica (silicon dioxide)	1650(±75)°C	Wikipedia <a href="http://en.wikipedia.org/wiki/Silicon_dioxide">http://en.wikipedia.org/wiki/Silicon_dioxide</a>
zirconia (zirconium dioxide)	2715°C	Wikipedia <a href="http://en.wikipedia.org/wiki/Zirconium_dioxide">http://en.wikipedia.org/wiki/Zirconium_dioxide</a>
Carbon	>300°C	Aldrich Catalog 2000-2001
alumina (aluminium oxide)	2072°C	Wikipedia <a href="http://en.wikipedia.org/wiki/Aluminium_oxide">http://en.wikipedia.org/wiki/Aluminium_oxide</a> (P. Patnaik (2002). Handbook of Inorganic Chemicals. McGraw-Hill.)
talc (hydrated magnesium silicate)	1500°C	Industrial Minerals Association - North America home page, <a href="http://www.ima-na.org/talc">http://www.ima-na.org/talc</a>
polyvinyl chloride	100–260°C	Wikipedia <a href="http://en.wikipedia.org/wiki/Polyvinyl_chloride">http://en.wikipedia.org/wiki/Polyvinyl_chloride</a> (Wilkes et al. (2005). PVC Handbook p. 414, Hanser Verlag.)
polyacrylic acid resin	106°C (Tg <sup>2)</sup> )	Aldrich Catalog 2000-2001
Polystyrene	240°C	Wikipedia <a href="http://en.wikipedia.org/wiki/Polystyrene">http://en.wikipedia.org/wiki/Polystyrene</a> (International Labour Organisation chemical safety card for polystyrene) <a href="http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/_icsc10/icsc1043.htm">http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/_icsc10/icsc1043.htm</a>
Polyethylene	130-145°C, 104-115°C, etc.	Aldrich Catalog 2000-2001

1) Since clay is a heterogeneous material, it does not have a proper melting point. However, a melting point of clay is obviously 100°C or higher.

2) Tg (Glass transition temperature) generally is lower than a melting point.

Accordingly, as shown in the above table, all the melting points (or Tg) of the materials claimed as possible surface coating materials are 100°C or higher. Therefore, the claimed surface coatings cannot be melted at 60°C to 100°C as stated in the specification of Maeda. One skilled in the art would understand that the reason for this discrepancy, again, is because of the mistranslation of the cited portion of Maeda cited by the Examiner.

### **Examples in Maeda**

Finally, the Examples in Maeda also show that it is not the melting of the surface that starts the curing reaction, but the melting of the solid amine. The Examples described Maeda are summarized in the following table:

Ex. No.	Solid amine (m.p. °C) Surface-coating (m.p. °C)	EXPERIMENTS FOR PROPERTIES (3) Gelation time (100°C)	Result (gelation time)
1	1,12-dodecanediamine (71°C)	melted	□ 10 sec
	polyvinyl chloride (100–260°C)	not melted	
2	1,12-dodecanediamine (71°C)	melted	□ 10 sec
	polyvinyl chloride (100–260°C)	not melted	
3	1,12-dodecanediamine (71°C)	melted	□ 10 sec
	polyvinyl chloride (100–260°C)	not melted	
4	1,12-dodecanediamine (71°C)	melted	□ 10 sec
	titanium oxide (>350°C)	not melted	
5	4,4'-diaminodiphenylmethane (91°C)	melted	□ 10 sec
	hydrophobic silica (1650(±75)°C)	not melted	
6	1,10-decanediamine (62°C)	melted	□ 10 sec
	titanium oxide (>350°C)	not melted	
7	1,12-dodecanediamine (71°C)	melted	□ 10 sec
	hydrophobic silica (1650(±75)°C)	not melted	

This data again shows that it is not the melting of the surface coating that starts the curing reaction, but the melting of the solid amine.

As explained above, the Examiner's rejection is based on a mistranslation and resulting misunderstanding of the Maeda reference. Since the combination of Maeda, as correctly understood by one of ordinary skill in the art, and Karkozov as stated by the Examiner would render Meada's

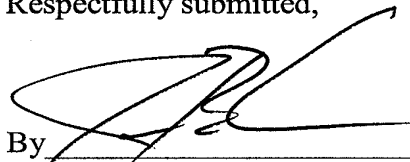
invention unsatisfactory for its intended purpose, the rejection of claims 1, 3-5, 8, 11, 13 and 15 should be withdrawn.

In view of the above, each of the claims in this application is in immediate condition for allowance. Accordingly, the Examiner is respectfully requested to withdraw the outstanding rejection of the claims and to pass this application to issue. If it is determined that a telephone conference would expedite the prosecution of this application, the Examiner is invited to telephone the undersigned at the number given below.

In the event that the transmittal form is separated from this document and the Patent and Trademark Office determines that an extension and/or other relief (such as payment of a fee under 37 C.F.R. § 1.17 (p)) is required, applicants petition for any required relief including extensions of time and authorize the Commissioner to charge the cost of such petition and/or other fees due in connection with the filing of this document to **Deposit Account No. 03-1952** referencing **Docket No. 358362011200**.

Dated: December 22, 2009

Respectfully submitted,



By  
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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of :  
T. Yoshida et al. : Group Art Unit 1796  
Serial No. 10/583,147 : Examiner: MCCULLEY, MEGAN  
CASSANDRA

Filed on August 2, 2007  
For Curable Composition

STATEMENT OF TRANSLATOR

Honorable Commissioner of Patent and Trademarks, Washington, D.C.

Sir,

I, the below named translator, hereby declare that:

My name and post office address are as stated below;

I am knowledgeable with both the Japanese and English languages and have been engaged in translation from Japanese into English in many technical fields for more than 20 years;

The specification of US Patent No. 5,866,668 is an English translation of WO 95/26374 published in Japanese. The phrase "the surface-coating of the solid amine" in the '668 specification at column 1, line 55 corresponds to the phrase "表面被覆された固形アミン" in WO 95/26374 at page 2, line 4.

The phrase "表面被覆された固形アミン" should not have been translated into the English phrase "the surface-coating of the solid amine" but should have been correctly translated into an English phrase "the surface-coated solid amine".

I conclude that the translated phrase "the surface-coating of the solid amine" is clearly a mistranslation of "表面被覆された固形アミン".

I hereby declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true.

Date: December 15, 2009

Full name of the translator: \_\_\_\_\_

  
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**A**  
ALDRICH

Handbook of Fine Chemicals and Laboratory Equipment  
**Aldrich**



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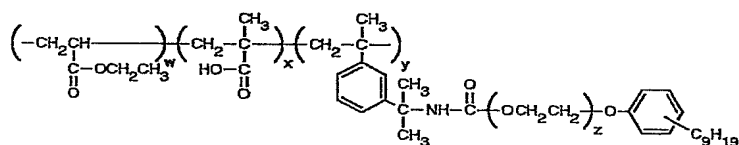
2000-2001

日本  
JAPAN  
¥

アルドリッチ  
総合カタログ

# ■ Polyethyl ■

✓ 45,815-5	★ Poly[ethyl acrylate-co-methacrylic acid-co-3-(1-isocyanato-1-methylethyl)- α-methylstyrene], adduct with ethoxylated nonylphenol, 25 wt. % solution in water [96828-31-8] bp 73° d 1.100 Fp none Alkali soluble associative thickener. Viscosity 10-100 cps. pH 2.5-4.5	1L	¥ 4,800	43,426
49,327-9	Poly(ethylene- <sup>13</sup> C <sub>2</sub> ), 99 atom % <sup>13</sup> C (- <sup>13</sup> CH <sub>2</sub> <sup>13</sup> CH <sub>2</sub> ) <sub>n</sub> mp 124-126°	100mg	220,700	43,427
48,700-7	Poly(ethylene-d <sub>4</sub> ), 98 atom % D [25549-98-8] (-CD <sub>2</sub> CD <sub>2</sub> ) <sub>n</sub> mp 125-128° Beil 1(3),637 HYGROSCOPIC	5g	145,800	42,77
✓ 26,935-2	★ Polyethylene, powder, spectrophotometric grade [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 130-145° Merck Index 12,7728 Safety 2,2871B R&S 1(2),3151A RTECS# TQ3325000	5g 25g	5,300 17,000	
42,802-7	★ Polyethylene, low density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> d 0.922 Merck Index 12,7728 RTECS# TQ3325000	1kg 3kg	5,400 11,800	42,77
✓ 42,803-5	★ Polyethylene, low density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 104-115° d 0.918 Merck Index 12,7728 RTECS# TQ3325000	1kg 3kg	5,400 11,800	42,77
✓ 42,804-3	★ Polyethylene, low density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 116° d 0.925 Merck Index 12,7728 RTECS# TQ3325000	250g 1kg	3,600 6,400	18,10
✓ 42,805-1	★ Polyethylene, low density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 115° d 0.923 Merck Index 12,7728 RTECS# TQ3325000	250g 1kg	3,600 6,400	44,86
✓ 42,807-8	★ Polyethylene, linear low density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 100-125° d 0.918 Merck Index 12,7728 RTECS# TQ3325000	1kg 3kg	5,000 10,900	42,67
✓ 42,808-6	★ Polyethylene, linear low density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 100-125° d 0.935 Merck Index 12,7728 RTECS# TQ3325000	1kg	5,000	42,67
✓ 42,810-8	★ Polyethylene, linear low density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 100-125° d 0.929 Merck Index 12,7728 RTECS# TQ3325000	1kg	4,900	42,67
✓ 33,211-9	★ Polyethylene, medium density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 109-111° d 0.940 Merck Index 12,7728 R&S 1(2),3151A RTECS# TQ3325000	25g 500g 1kg	4,200 12,900 21,800	42,67
✓ 18,190-0	★ Polyethylene, high density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> d 0.950 Merck Index 12,7728 FT-IR 1(2),1157B. Safety 2,2871B R&S 1(2),3151A RTECS# TQ3325000	25g 500g 1kg	4,700 8,100 14,000	42,67
✓ 42,796-9	★ Polyethylene, high density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 125-140° d 0.946 Merck Index 12,7728 RTECS# TQ3325000	1kg 3kg	4,800 10,300	
42,797-7	★ Polyethylene, high density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> Pellets. Melt index (190°C/2.16kg, ASTM D 1238) 4g/10min.	1kg 3kg	4,800 10,300	18,11
✓ 42,798-5	★ Polyethylene, high density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 125-140° d 0.952 Merck Index 12,7728 RTECS# TQ3325000	1kg 3kg	4,800 10,300	49,41
✓ 42,799-3	★ Polyethylene, high density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 125-140° d 0.962 Merck Index 12,7728 RTECS# TQ3325000	1kg 3kg	4,800 10,300	43,31
✓ 42,801-9	★ Polyethylene, high density [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> mp 121° d 0.947 Merck Index 12,7728 RTECS# TQ3325000	1kg 3kg	4,800 10,300	
✓ 42,901-5	★ Polyethylene, ultra-high molecular weight [9002-88-4] (-CH <sub>2</sub> CH <sub>2</sub> ) <sub>n</sub> d 0.940 Self-lubricating; extraordinary wear properties. Average M <sub>w</sub> 3,000,000-6,000,000. T <sub>m</sub> (DSC) 138°C	250g 1kg	3,500 7,800	45,6 43,4



45,815-5

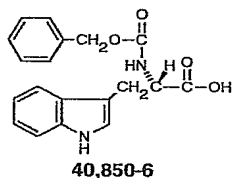
## ■ Calcium IC ■

		¥	#
... 100g	5,900	35,611-5 Calcium ICP/DCP standard solution d 1.035 Fp none CORROSIVE TOXIC .....	100mL 16,300
500g	23,200	Contains 10,000µg/mL of Ca in 1-2 wt. % HNO <sub>3</sub> . Exact Ca concentration on label .....	250mL 23,900
... 10g	6,500	42,886-8 Calcium matrix modifier solution, 99.9995% bp >100° d 1.060 Fp none.....	100mL 34,000
50g	21,500	★ CORROSIVE TOXIC	500mL 85,500
		Contains 2% Ca in 1 wt. % HNO <sub>3</sub>	
		For graphite furnace analyses	
.... 100mL	2,900	37,996-4 Calcium acetate hydrate, 99.99% [62-54-4] (CH <sub>3</sub> COO) <sub>2</sub> Ca·xH <sub>2</sub> O FW 158.17.....	5g 9,600
500mL	9,600	★ Fieser 13,60 15,46 Merck Index 12,1683 R&S 1(1),603E RTECS# AF7525000	25g 38,400
		HYGROSCOPIC	
		May contain up to 1% acetic acid	
... 5g	4,200	22,763-3 Calcium acetate hydrate, 99% [62-54-4] (CH <sub>3</sub> COO) <sub>2</sub> Ca·xH <sub>2</sub> O.....	5g 2,800
25g	8,800	★	100g 3,100
50g	8,400		500g 10,600
250g	30,200		
		40,285-0 Calcium acetate monohydrate, 99+%, A.C.S. reagent [5743-26-0].....	5g 4,100
		★ (CH <sub>3</sub> COO) <sub>2</sub> Ca·H <sub>2</sub> O FW 176.19 RTECS# AF7875000 HYGROSCOPIC	100g 4,700
		Assay ≥99.0%	500g 15,400
		Insolubles ≤0.005%	
		Titr. acid ≤0.035 meq/g	
		Alkalinity: to pass	
		Cl <sup>-</sup> ≤0.001%	
		Ba ≤0.01%	
		Fe ≤0.001%	
		K ≤0.01%	
		Sr ≤0.05%	
		Na ≤0.02%	
74 ... 5g	2,200	C10-7 Calcium acetylacetonate hydrate, 99.95% (2,4-pentanedione, calcium .....	5g 3,600
100g	3,800	derivative) [(CH <sub>3</sub> COCH=C(O)-CH <sub>3</sub> ) <sub>2</sub> Ca·xH <sub>2</sub> O FW 238.30 mp >280°(dec.)	25g 11,800
500g	12,300	Beil. 1(3),3120 R&S 1(2),3083A	
		x=0.5	
		35,964-5 Calcium L-ascorbate dihydrate, 99% [5743-28-2] (L-ascorbic acid, calcium salt	25g 2,700
		dihydrate) FW 426.35 mp 166°(dec.) [α] <sub>D</sub> +95° (c=5, H <sub>2</sub> O) Beil. 18(4),3045	100g 4,900
		FT-NMR 1(1),1150A R&S 1(1),813H	
		49,515-8 Calcium bis(6,6,7,7,8,8,8-heptafluoro-2,2-dimethyl-3,5-octanediolate), 99.99%.	5g 27,200
.... 1g	3,700	[36885-29-7] FW 630.44	25g 90,700
		NEW	
		36,295-6 Calcium bis(2,2,6,6-tetramethyl-3,5-heptanedionate) [118448-18-3].....	1g 6,800
IVE ... 5g	16,300	[(CH <sub>3</sub> ) <sub>3</sub> CCOCH=C(O)-C(CH <sub>3</sub> ) <sub>3</sub> ] <sub>2</sub> Ca FW 406.63 mp 221-224° FT-NMR 1(3),755A	5g 20,400
25g	61,800	R&S 1(2),3091D IRRITANT	
		Used in the preparation of thin-film superconductors. Aldrichimica Acta 1990, 23, 54.	
		5g 13,400	
25g	50,800	38,998-6 Calcium borohydride bis(tetrahydrofuran) Ca(BH <sub>4</sub> ) <sub>2</sub> ·2THF FW 213.98 .....	1g 3,600
		R&S 1(3),3261H FLAMMABLE SOLID CORROSIVE	5g 12,000
		5g 4,300	
100g	9,500	41,363-1 Calcium bromide, anhydrous, beads, -10 mesh, 99.98% [7789-41-5] CaBr <sub>2</sub> .....	1g 5,500
500g	32,200	★ FW 199.90 d 3.353 Merck Index 12,1693 R&S 1(3),3343L RTECS# EV9328000	5g 14,100
		MOISTURE-SENSITIVE IRRITANT	
		H <sub>2</sub> O <100 ppm	
		(Packaged under argon in ampules)	
25g	4,000	33,888-5 Calcium bromide, 96% [7789-41-5] CaBr <sub>2</sub> .....	25g 6,600
100g	11,000	★ Contains <2% water	250g 45,200
500g	33,100	23,374-9 Calcium bromide hydrate, 98% [71626-99-8] CaBr <sub>2</sub> ·xH <sub>2</sub> O FW 199.90 .....	5g 3,900
		★ R&S 1(3),3345A RTECS# EV9328000 HYGROSCOPIC	100g 4,600
		x≤1	500g 11,100
3 ..... 100mL	3,900	27,029-6 Calcium carbide, pieces, ~8mm thick, tech., ~80% [75-20-7] CaC <sub>2</sub> FW 64.10 .....	25g 4,100
30mL	9,700	★ d 2.220 Fieser 3,40 Merck Index 12,1696 Safety 2,665D R&S 1(3),3267A	500g 4,300
		RTECS# EV9400000 FLAMMABLE SOLID CORROSIVE	2kg 5,500
.... 100mL	3,800	49,202-7 Calcium carbonate- <sup>13</sup> C, 99 atom % <sup>13</sup> C Ca <sup>13</sup> CO <sub>3</sub> FW 101.08 mp 825° d 1.980.....	5g 126,700
500mL	9,300	IRRITANT HYGROSCOPIC	
		48,180-7 Calcium carbonate, 99.999+% [471-34-1] CaCO <sub>3</sub> FW 100.09 mp -800°(dec.) .....	5g 12,300
		★ d 2.930 Merck Index 12,1697 RTECS# FF9335000 IRRITANT	25g 40,700
		20,293-2 Calcium carbonate, 99.995+% [471-34-1] CaCO <sub>3</sub> .....	5g 7,400
		★	25g 27,700
			100g 73,300



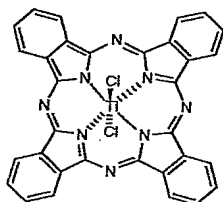
■ Carbobenzy ■

¥				¥
4,900	40,851-4	N-Carbobenzyloxy-L-threonine, 98% [19728-63-3].....	5g	5,000
16,200		CH <sub>3</sub> CH(OH)CH(NHCO <sub>2</sub> CH <sub>2</sub> C <sub>6</sub> H <sub>5</sub> )CO <sub>2</sub> H FW 253.26 mp 102-104°	25g	17,200
3,800		[α] <sub>D</sub> <sup>25</sup> -4.4° (c=4, CH <sub>3</sub> CO <sub>2</sub> H) Beil. 6(4),2389		
12,300	40,858-1	N-Carbobenzyloxy-L-threonine methyl ester, 98% [57224-63-2].....	1g	4,100
3,100		CH <sub>3</sub> CH(OH)CH(NHCO <sub>2</sub> CH <sub>2</sub> C <sub>6</sub> H <sub>5</sub> )CO <sub>2</sub> CH <sub>3</sub> FW 267.28 mp 92-94°	5g	13,400
9,800		[α] <sub>D</sub> <sup>25</sup> -18° (c=1, CH <sub>3</sub> OH) Beil. 6(3),1510		
3,600	40,850-6	Nα-Carbobenzyloxy-L-tryptophan, 99% [7432-21-5] FW 338.37 mp 125-127° .....	5g	4,300
12,800		[α] <sub>D</sub> <sup>25</sup> +2.9° (c=3, CH <sub>3</sub> CO <sub>2</sub> H) Beil. 22(4),6789	25g	13,100
2,100	47,059-7	N-Carbobenzyloxy-L-tyrosine, 97% [1164-16-5].....	5g	4,100
5,100		4-(HO)C <sub>6</sub> H <sub>4</sub> CH <sub>2</sub> CH(NHCO <sub>2</sub> CH <sub>2</sub> C <sub>6</sub> H <sub>5</sub> )CO <sub>2</sub> H FW 315.33 mp 89-94°	25g	14,300
5,700		[α] <sub>D</sub> <sup>22</sup> +11° (c=1, CH <sub>3</sub> CO <sub>2</sub> H) Beil. 14(3),1530		
21,600	29,352-0	Carbobenzyloxy-L-valine, 99% [1149-26-4] (CH <sub>3</sub> ) <sub>2</sub> CHCH(NHCO <sub>2</sub> CH <sub>2</sub> C <sub>6</sub> H <sub>5</sub> )CO <sub>2</sub> H ...	5g	3,600
5,700		FW 251.28 mp 62-64° [α] <sub>D</sub> <sup>25</sup> +6.5° (c=4, CHCl <sub>3</sub> ) Beil. 6(3),1502 R&S 1(2),18510		
5,700		Carbofuran, see 42,600-8, 2,3-Dihydro-2,2-dimethyl-7-benzofuranol N-methylcarbamate page 601		
21,600	29,387-3	Carbohydrates I, kit containing 31 standards HYGROSCOPIC .....	1kit	98,300
5,700		For a list of kit components, see the special section Kits		
19,500	C1,100-6	Carbohydrazide, 98% [497-18-7] H <sub>2</sub> NNHCONHNH <sub>2</sub> FW 90.09 mp 157-158° .....	25g	6,900
3,500	★	Beil. 3,121 Merck Index 12,1852 FT-IR 1(1),805A R&S 1(1),945B RTECS# FF2625000	100g	22,200
12,400		EXPLODES WHEN HEATED IRRITANT		
2,800	20,693-8	Carbol Fuchsin [4197-24-4] λ <sub>max</sub> 547nm Safety 2,683A R&S 1(2),2843A UV-Vis 188	5g	4,800
17,600		CANCER SUSPECT AGENT MUTAGEN	25g	17,000
4,600		A mixture of Basic Fuchsin and phenol		
15,100		(Carbomethoxymethyl)triphenylphosphorane, see 15,792-9, Methyl		
3,200		(triphenylphosphoranylidene)acetate page 1173		
10,500	25,906-3	(Carbomethoxymethyl)triphenylphosphonium bromide, 98% [1779-58-4].....	50g	8,800
4,600		CH <sub>3</sub> O <sub>2</sub> CCH <sub>2</sub> P(C <sub>6</sub> H <sub>5</sub> ) <sub>3</sub> Br FW 415.28 mp 172°(dec.) FT-NMR 1(2),1677C	250g	28,700
15,100		FT-IR 1(2),548D Safety 2,683C R&S 1(2),2279B IRRITANT HYGROSCOPIC		
2,700	46,772-3	(Carbomethoxymethyl)triphenylphosphonium chloride, 97% [2181-97-7].....	5g	2,400
6,400		CH <sub>3</sub> O <sub>2</sub> CCH <sub>2</sub> P(C <sub>6</sub> H <sub>5</sub> ) <sub>3</sub> Cl FW 370.82 mp 155°(dec.) IRRITANT HYGROSCOPIC	25g	8,000
3,100		3-(Carbomethoxy)propionyl chloride, see C1,104-9, Methyl 4-chloro-4-oxobutyrate page 1100		
5,100		Carbon, activated, see Activated carbon		
5,500	38,946-3	Carbon- <sup>12</sup> C, amorphous, 99.9 atom % <sup>12</sup> C [7440-44-0] <sup>12</sup> C FW 12.01 .....	250mg	7,100
16,800	★	Merck Index 12,1855 R&S 1(3),3217A RTECS# FF5250100 FLAMMABLE SOLID	1g	19,600
7,0		IRRITANT		
13,600		(Packaged in screw-cap bottles)		
4,100	27,720-7	Carbon- <sup>13</sup> C, amorphous, 99 atom % <sup>13</sup> C [14762-74-4] <sup>13</sup> C FW 13.00 d 3.510 .....	250mg†	23,300
15,100	NEW	Safety 2,684A R&S 1(3),3217B IRRITANT LIGHT-SENSITIVE	1g†	64,600
3,100		(Packaged in screw-cap bottles)		
5,100	48,416-4	Carbon, glassy, spherical powder, 2-12 micron, 99.99+% [7440-44-0] C .....	10g	5,100
5,500	NEW ★	Merck Index 12,1855 RTECS# FF5250100 IRRITANT	50g	13,600
16,800	48,415-6	Carbon, glassy, spherical powder, 10-40 micron, 99.99+% [7440-44-0] C .....	10g	5,100
7,0	NEW ★	mp >300° Merck Index 12,1855 RTECS# FF5250100 IRRITANT	50g	13,600
13,600	35,612-3	Carbon ICP/DCP standard solution d 1.011 Fp none IRRITANT .....	100mL	12,600
4,100		Contains 10,000µg/mL of C as citric acid in water. Exact C concentration on label		
15,100	36,459-2	Carbon- <sup>13</sup> C dioxide, 99 atom % <sup>13</sup> C [1111-72-4] <sup>13</sup> CO <sub>2</sub> FW 45.00 Fp none .....	250mL	19,400
3,100		R&S 1(1),827E NONFLAMMABLE GAS	1L	38,800
17,200		Important basic building block for <sup>13</sup> C labeled compounds.		
3,100		(Packaged in Sure/Pac™ cylinders)		
17,200	27,936-6	Carbon- <sup>13</sup> C dioxide, 99 atom % <sup>13</sup> C [1111-72-4] <sup>13</sup> CO <sub>2</sub> .....	250mL	31,000
3,100		(Packaged in break-seal flasks)	500mL	60,500
17,200			1L	86,000

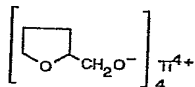


# ■ Titanium o ■

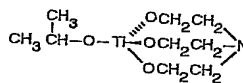
20,475-7	Titanium(IV) oxide, 99.99% [1317-80-2] TiO <sub>2</sub> .....	25g	9,600		
★	Predominantly rutile	125g	37,800		
✓ 48,449-0	Titanium(IV) oxide, mesoporous, 22Å pore, 99.95% [1317-80-2] TiO <sub>2</sub> FW 79.90...	1g	16,100		
★	mp >350° Merck Index 12,9612 RTECS# VM2940000	5g	53,500		
	Surface area ~1000 m <sup>2</sup> /g				
✓ 48,450-4	Titanium(IV) oxide, mesoporous, 32Å pore, 99.95% [1317-80-2] TiO <sub>2</sub> FW 79.90...	1g	16,100		
★	mp >350° Merck Index 12,9612 RTECS# VM2940000	5g	53,500		
	Surface area ~1000 m <sup>2</sup> /g				
22,422-7	Titanium(IV) oxide, powder, <5 micron, 99.9+% [1317-80-2] TiO <sub>2</sub> .....	5g	4,800		
★	Predominantly rutile	100g	8,300		
23,203-3	Titanium(IV) oxide, powder, 99.9+% [1317-70-0] TiO <sub>2</sub> FW 79.90 d 3.900 .....	500g	28,600		
★	Safety 2,3359A RTECS# XR2275000	100g	6,100		
	Anatase	500g	20,300		
24,857-6	Titanium(IV) oxide, -325 mesh, 99+% [1317-70-0] TiO <sub>2</sub> .....	100g	3,800		
★	Anatase	1kg	12,900		
		10kg	52,600		
33,083-3	Titanium(IV) oxide acetylacetonate [14024-64-7] [CH <sub>3</sub> COCH=C(O-)-CH <sub>3</sub> ] <sub>2</sub> TiO .....	10g	8,000		
★	FW 262.12 mp 200°(dec.) Beil. 1(4),3671 R&S 1(2),3085D RTECS# XR2330000	50g	29,900		
	IRRITANT				
49,537-9	Titanium(IV) oxysulfate, 99.99%, ca. 15 wt. % solution in dilute sulfuric acid .....	250mL	5,100		
★	[13825-74-6] TiOSO <sub>4</sub> FW 159.96 bp >100° d 1.361 Fp none Merck Index 12,9616	1L	14,100		
	HIGHLY TOXIC CANCER SUSPECT AGENT				
46,391-4	Titanium(IV) oxysulfate-sulfuric acid complex hydrate, 99.99% [123334-00-9]..	10g	9,100		
★	TiOSO <sub>4</sub> ·xH <sub>2</sub> SO <sub>4</sub> ·xH <sub>2</sub> O CORROSIVE TOXIC	50g	30,100		
33,398-0	Titanium oxysulfate-sulfuric acid complex hydrate [123334-00-9].....	100g	5,300		
	TiOSO <sub>4</sub> ·xH <sub>2</sub> SO <sub>4</sub> ·xH <sub>2</sub> O	500g	15,500		
51,174-9	Titanium(IV) phthalocyanine dichloride [16903-42-7] FW 631.35 mp >300° .....	5g	9,200		
★	λ <sub>max</sub> 692nm				
	Dye content ~95%				
25,308-1	Titanium(IV) propoxide, 98% [3087-37-4] (tetrapropyl orthotitanate).....	100g	9,800		
★	Ti(OCH <sub>2</sub> CH <sub>2</sub> CH <sub>3</sub> ) <sub>4</sub> FW 284.26 bp 170°/3mm n <sub>D</sub> <sup>20</sup> 1.4986 d 1.033 Fp 109°F(42°C)	500g	29,600		
	Beil. 1(3),1423 FT-IR 1(2),1281D Safety 2,3359C R&S 1(2),3055J				
	MOISTURE-SENSITIVE IRRITANT				
39,946-9	Titanium silicide, -325 mesh [12039-83-7] TiSi <sub>2</sub> FW 104.07 .....	25g	4,600		
★	Has both low and high resistivity phases; <sup>1</sup> used in the fabrication of transistors. <sup>2</sup> (1) J.				
	Appl. Phys. 1992, 72, 4978. (2) Trans. Electron Devices 1990, 37, 1444.				
49,518-2	Titanium(III) sulfate, 99.9+% , ca. 45 wt. % solution in dilute sulfuric acid .....	100mL	15,100		
★	[19495-80-8] Ti <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> FW 383.99 d 1.456 Fp none HIGHLY TOXIC				
	CANCER SUSPECT AGENT				
33,349-2	Titanium(IV) sulfide, powder, ca. 1 micron, 99.9% [12039-13-3] TiS <sub>2</sub> FW 112.03..	10g	15,200		
★	R&S 1(3),3299B MOISTURE-SENSITIVE IRRITANT	50g	59,100		
51,703-8	Titanium tetrachloride, see 20,856-6, Titanium(IV) chloride page 1612				
✓ 51,703-8	Titanium(IV) tetrahydrofurfuryloxide, 50 wt. % solution in tetrahydrofurfuryl .....	100mL	25,100		
★	alcohol and isopropanol [22290-53-5] FW 452.41 bp 178° n <sub>D</sub> <sup>20</sup> 1.4930 d 1.140				
38,817-3	Titanium(IV) (triethanolaminato)isopropoxide, 80 wt. % solution in 2-propanol...	100mL	2,300		
★	[74665-17-1] (TYZOR® TE organic titanate) FW 253.16 d 1.087 Fp 61°F(16°C)	500mL	7,500		
	FLAMMABLE LIQUID IRRITANT				
	DuPont product				
	Titan Yellow, see 20,204-5, Thiazol Yellow G page 1596				
40,455-1	Titanyl phthalocyanine [26201-32-1] FW 576.44 λ <sub>max</sub> 692nm IRRITANT .....	250mg	4,300		
★	Dye content ~95%	1g	12,000		
	TMAC, see T6,802-0, Trimellitic anhydride acid chloride page 1668				
	TMB, see 3,3',5,5'-Tetramethylbenzidine				



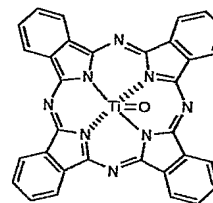
51,174-9



51,703-8



38,817-3



40,455-1

TMB-4, bromic  
TMB-8, chloric  
TMCS,  
TMCTE  
TMED/  
TMO, s  
TMP, s  
TMPT/  
TMPTI  
TMS, s  
TMSCI  
TMSCI  
TMSDI  
TMSI,  
TMTD,  
TMTSI  
TNBT,  
TNM,  
TNS, s  
page  
α-Toci  
Tolan,  
29,349-0 Tolaz  
Beil. 2  
R&S  
T3,546-7 Tolaz  
FW 1:  
Safet  
T3,547-5 o-Toli  
FW 2  
CAN  
34,555-5 o-Toli  
benz  
R&S  
Ignit  
Sol  
Sen  
T3,548-3 o-Toli  
[C<sub>6</sub>H  
FT-IF  
CAN  
38,036-9 o-Toli  
dihy  
RTE  
47,629-3 m-Tol  
dihy  
IRRI  
47,636-6 o-Toli  
thio  
Mixt  
Tolor  
11,755-2 o-Toli  
d 1.0  
Safe

# ■ Polyacryli ■

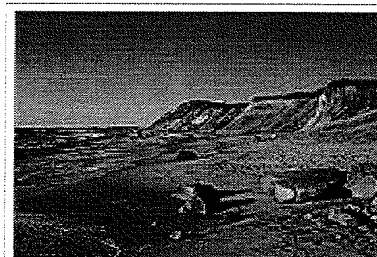
32,366-7	★	Poly(acrylic acid) [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	5g	4,100	
		Powder. Average M <sub>w</sub> ca. 2,000 (GPC)	100g	13,400	
			250g	24,900	
✓ 18,128-5	★	Poly(acrylic acid) [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	5g	4,000	
		Powder. Approx. 0.1% cross-linked. Average M <sub>v</sub> ca. 450,000. Tg 106°. Contains ≤0.5% benzene	100g	15,600	
			250g	28,900	
30,620-7	★	Poly(acrylic acid) [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	5g	4,000	
		Powder. Approx. 0.1% cross-linked. Average M <sub>v</sub> ca. 750,000. Tg 106°. Contains ≤0.5% benzene	100g	10,100	
			250g	17,100	
30,621-5	★	Poly(acrylic acid) [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	5g	4,400	
		Powder. Approx. 0.1% cross-linked. Average M <sub>v</sub> ca. 1,250,000. Tg 106°	100g	11,200	
			250g	18,900	
30,622-3	★	Poly(acrylic acid) [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	5g	4,000	
		Powder. Approx. 0.1% cross-linked. Average M <sub>v</sub> ca. 3,000,000. Tg 106°	100g	10,100	
			250g	17,100	
30,623-1	★	Poly(acrylic acid) [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	5g	4,400	
		Powder. Approx. 0.1% cross-linked. Average M <sub>v</sub> ca. 4,000,000. Tg 106°	100g	11,200	
			250g	18,900	
52,392-5	★	Poly(acrylic acid), 35 wt. % solution in water [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	100mL	5,000	
		d 1.140	500mL	17,400	
		Average M <sub>w</sub> ca. 100,000			
41,600-2	★	Poly(acrylic acid), 35 wt. % solution in water [9003-01-4] [-CH <sub>2</sub> CH(CO <sub>2</sub> H)-] <sub>n</sub> .....	5mL	4,000	
		Average M <sub>w</sub> ca. 250,000	250mL	10,400	
			500mL	17,400	
19,202-3	★	Poly(acrylic acid), partial sodium salt, 60 wt. % solution in water [9033-79-8] ...	5g	4,900	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> R)-] <sub>n</sub> , R = H or Na n <sub>D</sub> <sup>20</sup> 1.4420 Safety 2,2859D R&S 1(2),3163F	250g	9,200	
		RTECS# AT4680000 IRRITANT	500g	16,500	
		Viscous liquid. Average M <sub>w</sub> ca. 2,000 (GPC). Contains ca. 0.6% Na			
19,203-1	★	Poly(acrylic acid), partial sodium salt, 50 wt. % solution in water [9033-79-8] ...	5g	4,900	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> R)-] <sub>n</sub> , R = H or Na	250g	9,200	
		Viscous liquid. Average M <sub>w</sub> ca. 5,000 (GPC). Contains ca. 0.5% Na	500g	16,500	
19,205-8	★	Poly(acrylic acid), partial sodium salt, 25 wt. % solution in water [9033-79-8] ...	5g	3,700	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> R)-] <sub>n</sub> , R = H or Na	250g	9,200	
		Viscous liquid. Average M <sub>w</sub> ca. 240,000 (GPC). Contains ca. 0.3% Na	500g	16,500	
43,532-5	★	Poly(acrylic acid), partial potassium salt, lightly cross-linked [25608-12-2] .....	250g	3,900	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> R)-] <sub>n</sub> , R = H or K d 0.400	1kg	9,400	
		Superabsorbent polymer. Absorbs aqueous fluids more rapidly than corresponding sodium salt, 43,636-4. Absorbs ca. 27g of 1% saline solution/g. Particle size 99% <1,000μm			
44,701-3	★	Poly(acrylic acid, sodium salt) [9003-04-7] [-CH <sub>2</sub> CH(CO <sub>2</sub> Na)-] <sub>n</sub> d 0.550 IRRITANT	100g	4,000	
		HYGROSCOPIC	500g	13,500	
		Powder. Average M <sub>w</sub> ca. 5,100 (GPC)			
42,034-4	★	Poly(acrylic acid, sodium salt) [9003-04-7] [-CH <sub>2</sub> CH(CO <sub>2</sub> Na)-] <sub>n</sub> .....	100g	5,400	
		Average M <sub>w</sub> ca. 2,100	500g	17,800	
41,601-0	★	Poly(acrylic acid, sodium salt), 45 wt. % solution in water [9003-04-7] .....	100mL	4,800	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> Na)-] <sub>n</sub>	500mL	15,700	
		Average M <sub>w</sub> ca. 1,200			
41,602-9	★	Poly(acrylic acid, sodium salt), 45 wt. % solution in water [9003-04-7] .....	100mL	5,200	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> Na)-] <sub>n</sub>	500mL	17,000	
		Average M <sub>w</sub> ca. 8,000			
41,604-5	★	Poly(acrylic acid, sodium salt), 40 wt. % solution in water [9003-04-7] .....	100mL	4,800	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> Na)-] <sub>n</sub>	500mL	15,700	
		Average M <sub>w</sub> ca. 30,000			
41,603-7	★	Poly(acrylic acid, sodium salt), 35 wt. % solution in water [9003-04-7] .....	100mL	4,800	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> Na)-] <sub>n</sub>	500mL	15,700	
		Average M <sub>w</sub> ca. 15,000			
43,636-4	★	Poly(acrylic acid), partial sodium salt, lightly cross-linked [76774-25-9] .....	250g	3,900	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> R)-] <sub>n</sub> , R = H or Na d 0.690 IRRITANT	1kg	8,900	
		Superabsorbent polymer. Absorbs more aqueous fluid than corresponding potassium salt, 43,532-5. Absorbs ca. 45g of 1% saline solution/g. Particle size 99% <1,000μm			
43,277-6	★	Poly(acrylic acid-co-acrylamide), potassium salt, cross-linked [90363-65-8] .....	250g	4,500	
		[-CH <sub>2</sub> CH(CO <sub>2</sub> R)-] <sub>x</sub> [-CH <sub>2</sub> CH(CONH <sub>2</sub> )-] <sub>y</sub> , R=H or K d 0.540 MOISTURE-SENSITIVE IRRITANT	1kg	9,800	
		Superabsorbent polymer. Granules. 200-1,000 microns. pH 5.5-6.0			
		Poly(acrylic acid 6-aminohexylamide), see 23,125-8, 1-Aminoheptylamide gel page 79			



# Clay

From Wikipedia, the free encyclopedia

**Clay** is a naturally occurring material composed primarily of fine-grained minerals, which show plasticity through a variable range of water content, and which can be hardened when dried and/or fired. Clay deposits are mostly composed of clay minerals (phyllosilicate minerals), minerals which impart plasticity and harden when fired and/or dried, and variable amounts of water trapped in the mineral structure by polar attraction. Organic materials which do not impart plasticity may also be a part of clay deposits.<sup>[1]</sup>



The Gay Head cliffs in Martha's Vineyard consist almost entirely of clay.

## Contents

- 1 Formation
- 2 Definition
- 3 Grouping
- 4 Historical and modern uses
  - 4.1 Medical and agricultural uses
- 5 See also
- 6 Footnotes
- 7 References
- 8 External links

## Formation

Clay minerals are typically formed over long periods of time by the gradual chemical weathering of rocks, usually silicate-bearing, by low concentrations of carbonic acid and other diluted solvents. These solvents, usually acidic, migrate through the weathering rock after leaching through upper weathered layers. In addition to the weathering process, some clay minerals are formed by hydrothermal activity. Clay deposits may be formed in place as residual deposits, but thick deposits usually are formed as the result of a secondary sedimentary deposition process after they have been eroded and transported from their original location of formation. Clay deposits are typically associated with very low energy depositional environments such as large lake and marine deposits.

Primary clays, also known as kaolins, are located at the site of formation. Secondary clay deposits have been moved by erosion and water from their primary location<sup>[2]</sup>.

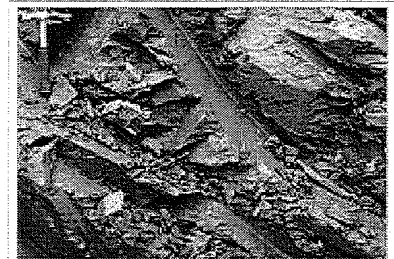
## Definition

Clays are distinguished from other fine-grained soils by differences in size and/or

mineralogy. Silts, which are fine-grained soils which do not include clay minerals, tend to have larger particle sizes than clays, but there is some overlap in both particle size and other physical properties, and there are many naturally occurring deposits which include both silts and clays. The distinction between silt and clay varies by discipline. Geologists and soil scientists usually consider the separation to occur at a particle size of 2  $\mu\text{m}$  (clays being finer than silts), sedimentologists often use 4–5  $\mu\text{m}$ , and colloid chemists use 1  $\mu\text{m}$ .<sup>[1]</sup> Geotechnical engineers distinguish between silts and clays based on the plasticity properties of the soil, as measured by the soils' Atterberg Limits. ISO 14688 grades clay particles as being smaller than 0.002 mm and silts larger.

## Grouping

Depending on the academic source, there are three or four main groups of clays: kaolinite, montmorillonite-smectite, illite, and chlorite. Chlorites are not always considered a clay, sometimes being classified as a separate group within the phyllosilicates. There are approximately thirty different types of "pure" clays in these categories, but most "natural" clays are mixtures of these different types, along with other weathered minerals.



Quaternary clay in Estonia.

Varve (or *varved clay*) is clay with visible annual layers, formed by seasonal differences in erosion and organic content. This type of deposit is common in former glacial lakes.

Quick clay is a unique type of marine clay indigenous to the glaciated terrains of Norway, Canada, Northern Ireland and Sweden. It is a highly sensitive clay, prone to liquefaction, which has been involved in several deadly landslides.

## Historical and modern uses

Clays exhibit plasticity when mixed with water in certain proportions. When dry, clay becomes firm and when fired in a kiln, permanent physical and chemical reactions occur. These reactions, among other changes, cause the clay to be converted into a ceramic material. Because of these properties, clay is used for making pottery items, both practical and decorative. Different types of clay, when used with different minerals and firing conditions, are used to produce earthenware, stoneware, and porcelain. Prehistoric humans discovered the useful properties of clay, and one of the earliest artifacts ever uncovered is a drinking vessel made of sun-dried clay. Depending on the content of the soil, clay can appear in various colors, from a dull gray to a deep orange-red.



Clay layers in a construction site. Dry clay is normally much more stable than sand with regard to excavations.

Clay tablets were used as the first writing medium, inscribed with cuneiform script through the use of a blunt reed called a stylus.

Clays sintered in fire were the first form of ceramic. Bricks, cooking pots, art objects, dishware and even musical instruments such as the ocarina can all be shaped from clay before being fired. Clay is also used in many industrial processes, such as paper making,



cement production and chemical filtering. Clay is also often used in the manufacture of pipes for smoking tobacco.

Clay, being relatively impermeable to water, is also used where natural seals are needed, such as in the cores of dams, or as a barrier in landfills against toxic seepage ('lining' the landfill, preferably in combination with geotextiles).<sup>[3]</sup>

Recent studies have investigated clay's absorption capacities in various applications, such as the removal of heavy metals from waste water and air purification.

## Medical and agricultural uses

A traditional use of clay, such as Armenian bole, is to soothe an upset stomach, similar to the way parrots (and later, humans) in South America originally used it.<sup>[4]</sup>

A more recent, and more limited, use is as a specially formulated spray applied to fruits, vegetables and other vegetation to repel or deter codling moth damage, and at least for apples, to prevent sun scald.

A recent article in *The Journal of Antimicrobial Chemotherapy* found that certain iron-rich clay was effective in killing bacteria.<sup>[5]</sup>

## See also

- Bentonite
- Ceramic
- Clay (industrial plasticine)
- Clay animation
- Clay court
- Clay minerals
- Clay pit
- Geophagy (eating of soils, including eating of clay)
- Expansive clay
- Graham Cairns-Smith, proposed the 'clay theory' of abiogenesis
- List of minerals
- London Clay
- Modelling clay
- Paperclay
- Particle size
- Plasticine
- Pottery
- Vertisol

## Footnotes

1. <sup>a b</sup> Guggenheim & Martin 1995, pp. 255–256
2. <sup>^</sup> Environmental Characteristics of Clays and Clay Mineral Deposits (<http://pubs.usgs.gov/info/clays/>)
3. <sup>^</sup> *Preliminary evaluation of a compacted bentonite / sand mixture as a landfill liner material (Abstract)* (<http://www2.widener.edu/~sxw0004/abstract34.html>) - Koçkar, Mustafa K.; Akgün, Haluk; Aktürk, Özgür; Department of Geological Engineering, Middle East Technical University, Ankara, Turkey
4. <sup>^</sup> [http://cogweb.ucla.edu/Abstracts/Diamond\\_99.html](http://cogweb.ucla.edu/Abstracts/Diamond_99.html) Evolutionary biology: Dirty eating for healthy living by Jared M. Diamond
5. <sup>^</sup> <http://jac.oxfordjournals.org/cgi/content/abstract/61/2/353> Broad-spectrum in vitro antibacterial activities of clay minerals against antibiotic-susceptible and antibiotic-resistant bacterial pathogens

## References

- Guggenheim, Stephen; Martin, R. T. (1995), "Definition of clay and clay mineral: Journal report of the AIPEA nomenclature and CMS nomenclature committees (<http://www.clays.org/journal/archive/volume%2043/43-2-255.pdf>) ", *Clays and Clay Minerals* **43**: 255–256, doi:10.1346/CCMN.1995.0430213 (<http://dx.doi.org/10.1346/2FCCMN.1995.0430213>) , <http://www.clays.org/journal/archive/volume%2043/43-2-255.pdf>
- Clay mineral nomenclature ([http://www.minsocam.org/msa/collectors\\_corner/arc/nomenclaturecl1.htm](http://www.minsocam.org/msa/collectors_corner/arc/nomenclaturecl1.htm)) *American Mineralogist*.
- Ehlers, Ernest G. and Blatt, Harvey (1982). 'Petrology, Igneous, Sedimentary, and Metamorphic' San Francisco: W.H. Freeman and Company. ISBN 0-7167-1279-2.
- Hillier S. (2003) Clay Mineralogy. pp 139–142 In: Middleton G.V., Church M.J., Coniglio M., Hardie L.A. and Longstaffe F.J.(Editors) Encyclopedia of sediments and sedimentary rocks. Kluwer Academic Publishers, Dordrecht.

## External links

- Building the Phyllosilicates (<http://pubpages.unh.edu/~harter/crystal.htm>) University of New Hampshire
- The Clay Minerals Group of the Mineralogical Society (<http://www.minersoc.org/pages/groups/cmg/cmg.html>)
- Historical information about the clays of North Staffordshire, UK (<http://www.stoke.gov.uk/ccm/museums/museum/2006/gladstone-pottery-museum/information-sheets/clay-in-north-staffordshire.en>)
- Information about clays used in the UK pottery industry (<http://www.stoke.gov.uk/ccm/museums/museum/2006/gladstone-pottery-museum/information-sheets/clays-used-in-the-pottery-industry.en>)
- The Clay Minerals Society (<http://www.clays.org/>)

Retrieved from "<http://en.wikipedia.org/wiki/Clay>"

Categories: Sculpture materials | Natural materials | Sedimentology | Sediments | Silicate minerals | Types of soil | Ceramic materials

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# Silicon dioxide

From Wikipedia, the free encyclopedia  
(Redirected from Silica)

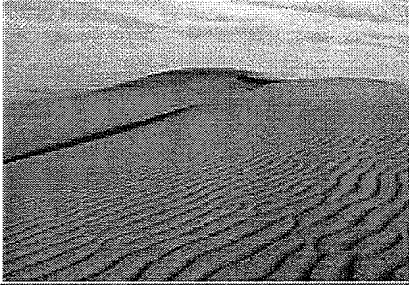
The chemical compound **silicon dioxide**, also known as **silica** (from the Latin *sil**ex*), is an oxide of silicon with a chemical formula of **SiO<sub>2</sub>** and has been known for its hardness since antiquity.<sup>[1]</sup> Silica is most commonly found in nature as sand or quartz, as well as in the cell walls of diatoms. It is a principal component of most types of glass and substances such as concrete. Silica is the most abundant mineral in the Earth's crust.

## Contents

- 1 Structure and properties
- 2 Molecular forms of silicon dioxide
- 3 Chemistry
- 4 Manufactured forms
- 5 Applications
- 6 Health effects
- 7 References
- 8 Further reading
- 9 See also
- 10 External links

## Structure and properties

SiO<sub>2</sub> has a number of distinct crystalline forms in addition to amorphous forms. With the exception of stishovite and fibrous silica, all of the crystalline forms involve tetrahedral SiO<sub>4</sub> units linked together by shared vertices in different arrangements. Silicon-oxygen bond lengths vary between the different crystal forms, for example in α-quartz the bond length is 161 pm, whereas in α-tridymite it is in the range 154-171 pm.<sup>[2]</sup> The Si-O-Si angle also varies between a low value of 140° in α-tridymite, up to 180° in β-tridymite. In α-quartz the Si-O-Si angle is 144°.

Silicon dioxide	
	
Other names	Silica quartz
Identifiers	
CAS number	7631-86-9 ✓
ChemSpider ID	22683
Properties	
Molecular formula	SiO <sub>2</sub>
Molar mass	60.0843 g/mol
Appearance	white powder
Density	2.634 g/cm <sup>3</sup>
Melting point	<u>1650(±75) °C</u> ✓
Boiling point	2230 °C
Solubility in water	0.012 g/100 mL
Structure	
Crystal structure	<i>see text</i>
Molecular shape	linear (gas-phase)
Hazards	
EU Index	Not listed
Main hazards	inhalation of fine powders can damage the respiratory tract
Flash point	Non-flammable
Related compounds	
Other anions	Silicon sulfide
Other cations	Carbon dioxide Germanium dioxide Tin dioxide Lead dioxide
Related silicon oxides	Silicon monoxide
Related compounds	Silicic acid "Silica gel"

Fibrous sulfur has a structure similar to that of  $\text{SiS}_2$  with chains of edge-sharing  $\text{SiO}_4$  tetrahedra. Stishovite, the highest pressure form, in contrast has a rutile like structure where silicon is 6 coordinate. The density of stishovite is  $4.287 \text{ g/cm}^3$ , which compares to  $\alpha$ -quartz, the densest of the low pressure forms, which has a density of  $2.648 \text{ g/cm}^3$ .<sup>[3]</sup> The difference in density can be ascribed to the increase in coordination as the six shortest Si-O bond lengths in stishovite (four Si-O bond lengths of 176 pm and two others of 181 pm) are greater than the Si-O bond length (161 pm) in  $\alpha$ -quartz.<sup>[4]</sup> The change in the coordination increases the ionicity of the Si-O bond.<sup>[5]</sup>

✓ (what is this?) (verify) ([http://en.wikipedia.org/w/index.php?title=Silicon\\_dioxide&diff=cur&oldid=269527166](http://en.wikipedia.org/w/index.php?title=Silicon_dioxide&diff=cur&oldid=269527166))

Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)

Infobox references

Note that the only stable form under normal conditions is  $\alpha$ -quartz and this is the form in which crystalline silicon dioxide is usually encountered.<sup>[3]</sup> In nature impurities in crystalline  $\alpha$ -quartz can give rise to colours<sup>[3]</sup> (see quartz for a list).

Faujasite-silica is another form of crystalline silica. It is obtained by dealumination of a low-sodium, ultra-stable Y zeolite with a combined acid and thermal treatment. The resulting product contains over 99% silica, has high crystallinity and high surface area (over  $800 \text{ m}^2/\text{g}$ ). Faujasite-silica has very high thermal and acid stability (it maintains high crystallinity even after boiling in concentrated hydrochloric acid).<sup>[6]</sup>

**Crystalline forms of SiO<sub>2</sub>**<sup>[2]</sup>

Form	Crystal Class	Structural features	Notes
$\alpha$ -quartz	rhombohedral (trigonal)	Helical chains making individual single crystals optically active	$\alpha$ -quartz converts to $\beta$ -quartz at 573 °C
$\beta$ -quartz	hexagonal	closely related to $\alpha$ -quartz (with an Si-O-Si angle of 155°) and optically active	$\beta$ -quartz converts to $\beta$ -tridymite at 870 °C
$\alpha$ -tridymite	orthorhombic	metastable form under normal pressure	
$\beta$ -tridymite	hexagonal	closely related to $\alpha$ -tridymite	$\beta$ -tridymite converts to $\beta$ -cristobalite at 1470 °C
$\alpha$ -cristobalite	tetragonal	metastable form under normal pressure	
$\beta$ -cristobalite	cubic	closely related to $\alpha$ -cristobalite	melts at 1705 °C
keatite	tetragonal	Si <sub>5</sub> O <sub>10</sub> , Si <sub>4</sub> O <sub>14</sub> , Si <sub>8</sub> O <sub>16</sub> rings	synthesised from amorphous silica and alkali at high pressure
coesite	monoclinic	Si <sub>4</sub> O <sub>8</sub> and Si <sub>8</sub> O <sub>16</sub> rings	high pressure form (higher than keatite)
stishovite	tetragonal	rutile like with 6-fold coordinated Si	high pressure form (higher than coesite) and the densest of the polymorphs
melanophlogite	cubic	Si <sub>5</sub> O <sub>10</sub> , Si <sub>6</sub> O <sub>12</sub> rings	mineral always found with hydrocarbons in interstitial spaces-a clathrasil <sup>[7]</sup>
fibrous	orthorhombic	like SiS <sub>2</sub> consisting of edge sharing chains	
faujasite	cubic	sodalite cages connected by hexagonal prisms; 12-membered ring pore opening; faujasite structure. <sup>[6]</sup>	

Molten silica exhibits several peculiar physical characteristics that are similar to the ones observed in liquid water: negative temperature expansion, density maximum and a heat capacity minimum.<sup>[8]</sup>

## Molecular forms of silicon dioxide

When molecular silicon monoxide, SiO, is condensed in an argon matrix cooled with helium along with oxygen atoms generated by microwave discharge, molecular SiO<sub>2</sub> is produced which has a linear structure.<sup>[9]</sup> The Si-O bond length is 148.3 pm which compares with the length of 161 pm in α-quartz. The bond energy is estimated at 621.7 kJ/mol.<sup>[9]</sup>

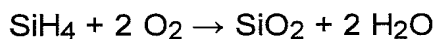
Dimeric silicon dioxide, (SiO<sub>2</sub>)<sub>2</sub> has been prepared by reacting O<sub>2</sub> with matrix isolated dimeric silicon monoxide, (Si<sub>2</sub>O)<sub>2</sub>.<sup>[9]</sup> In dimeric silicon dioxide there are two oxygen atoms bridging between the silicon atoms with an Si-O-Si angle of 94° and bond length of 164.6 pm and the terminal Si-O bond length is 150.2 pm.<sup>[9]</sup>

## Chemistry

Silicon dioxide is formed when silicon is exposed to oxygen (or air). A very thin layer (approximately 1 nm or 10 Å) of so-called 'native oxide' is formed on the surface when silicon is exposed to air under ambient conditions. Higher temperatures and alternative environments are used to grow well-controlled layers of silicon dioxide on silicon, for example at temperatures between 600 and 1200 °C, using the so-called "dry" or "wet" oxidation with O<sub>2</sub> or H<sub>2</sub>O, respectively.<sup>[10]</sup> The thickness of the layer of silicon replaced by the dioxide is 44% of the thickness of the silicon dioxide layer produced.<sup>[10]</sup>

Alternative methods used to deposit a layer of SiO<sub>2</sub> include:<sup>[11]</sup>

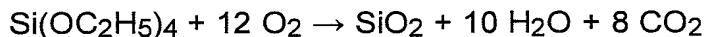
- Low temperature oxidation (400–450 °C) of silane



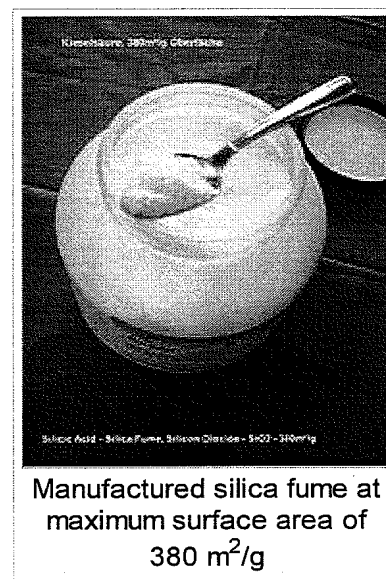
- Decomposition of tetraethyl orthosilicate (TEOS) at 680–730 °C



- Plasma enhanced chemical vapor deposition using TEOS at about 400 °C



- Polymerization of tetraethyl orthosilicate (TEOS) at below 100 °C using amino acid as catalyst.<sup>[12]</sup>



Pyrogenic silica (sometimes called fumed silica or silica fume), which is a very fine particulate form of silicon dioxide, is prepared by burning  $\text{SiCl}_4$  in an oxygen rich hydrocarbon flame to produce a "smoke" of  $\text{SiO}_2$ .<sup>[3]</sup>

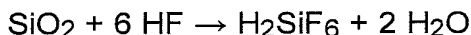


Amorphous silica, silica gel, is produced by the acidification of solutions of sodium silicate to produce a gelatinous precipitate that is then washed and then dehydrated to produce colorless microporous silica.<sup>[3]</sup>

Quartz exhibits a maximum solubility in water at temperatures about 340 °C.<sup>[13]</sup> This property is used to grow single crystals of quartz in a hydrothermal process where natural quartz is dissolved in superheated water in a pressure vessel which is cooler at the top. Crystals of 0.5–1 kg can be grown over a period of 1–2 months.<sup>[2]</sup> These crystals are a source of very pure quartz for use in electronic applications.<sup>[3]</sup>

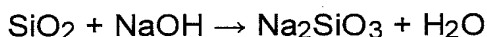
Fluorine reacts with silicon dioxide to form  $\text{SiF}_4$  and  $\text{O}_2$  whereas the other halogen gases ( $\text{Cl}_2$ ,  $\text{Br}_2$ ,  $\text{I}_2$ ) react much less readily.<sup>[3]</sup>

Silicon dioxide is attacked by hydrofluoric acid (HF) to produce "hexafluorosilicic acid".<sup>[2]</sup>

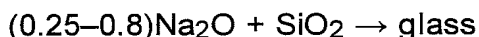
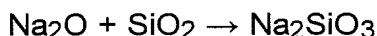
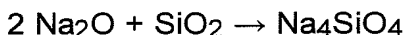


HF is used to remove or pattern silicon dioxide in the semiconductor industry.

Silicon dioxide dissolves in hot concentrated alkali or fused hydroxide.<sup>[3]</sup>

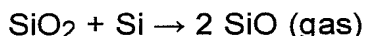


Silicon dioxide reacts with basic metal oxides (e.g. sodium oxide, potassium oxide, lead(II) oxide, zinc oxide or mixtures of oxides forming silicates and glasses as the Si-O-Si bonds in silica are broken successively).<sup>[2]</sup> As an example the reaction of sodium oxide and  $\text{SiO}_2$  can produce sodium orthosilicate, sodium silicate and glasses, depending on the proportions of reactants.<sup>[3]</sup>



Examples of such glasses have commercial significance e.g. soda lime glass, borosilicate glass, lead glass. In these glasses, silica is termed the network former or lattice former.<sup>[2]</sup>

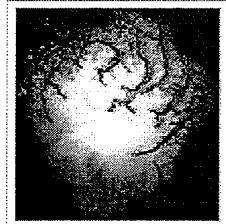
With silicon at high temperatures gaseous SiO is produced:<sup>[2]</sup>



## Manufactured forms

Silica is manufactured in several forms including:

- Glass (a colorless, high-purity form is called *fused silica*)
- Synthetic amorphous silica, silica gel
- Fumed silica (also known as pyrogenic silica, colloidal silica, or under the genericized trademark, AEROSIL)
- Precipitated silica is produced by precipitation from a waterglass solution by acidification.
- Silica aerogel.
- Silica Nanosprings<sup>TM</sup> are produced by Vapor-Liquid-Solid method at temperatures as low as room temperature.<sup>[14]</sup>



Fumed silica  
with surface  
area of 130  
m<sup>2</sup>/g.

## Applications

Silica is used in the production of various products.

- Inexpensive soda-lime glass is the most common and typically found in drinking glasses, bottles, and windows.
- Majority of optical fibers for telecommunications are made from silica.
- A raw material for many whiteware ceramics such as earthenware, stoneware and porcelain.
- A raw material for the production of Portland cement.
- A food additive, primarily as a flow agent in powdered foods, or to absorb water (see the ingredients list for).
- It is the primary component of diatomaceous earth which has many uses ranging from filtration to insect control.
- An oxide layer grown on silicon is hugely beneficial in microelectronics. It is a superior electric insulator, with high chemical stability. In electrical applications, it can protect the silicon, store charge, block current, and even act as a controlled pathway to allow small currents to flow through a device. The traditional method of manufacture such an oxide layer has been to heat the silicon in a high-temperature furnaces within an oxygen ambient (thermal oxidation).
- Raw material for aerogel in the Stardust spacecraft
- Used in the extraction of DNA and RNA due to its ability to bind to the nucleic acids under the presence of chaotropes.
- As hydrophobic silica it is used as a defoamer component.
- As hydrated silica in toothpaste (abrasive to remove plaque.)
- As a high-temperature thermal protection fabric.
- In cosmetics for its light-diffusing properties and its absorbency.
- Liquid silicon dioxide (colloidal silica) is used as a wine and juice fining agent.
- As a glidant in pharmaceutical products silicon dioxide aids powder flow when tablets are formed.
- In the production of tires
- Thermal enhancement compound used in thermal grouts for the ground source heat pump industry.

## Health effects

Inhaling finely divided crystalline silica dust in very small quantities (OSHA allows 0.1 mg/m<sup>3</sup>) over time can lead to silicosis, bronchitis or (much more rarely) cancer, as the dust becomes lodged in the lungs and continuously irritates them, reducing lung capacities



(silica does not dissolve over time). This effect can be an occupational hazard for people working with sandblasting equipment, products that contain powdered crystalline silica and so on. Children, asthmatics of any age, allergy sufferers and the elderly (all of whom have reduced lung capacity) can be affected in much shorter periods of time. Amorphous silica, such as fumed silica is not associated with development of silicosis.<sup>[15]</sup> Laws restricting silica exposure with respect to the silicosis hazard specify that the silica is both crystalline and dust-forming.

In respects other than inhalation, pure silicon dioxide is inert and harmless. Because some silicas take on water, extended exposure may cause local drying of the skin or other tissue. Pure silicon dioxide produces no fumes and is insoluble *in vivo*. (*in vivo* is a latin term meaning "within the living") It is indigestible, with zero nutritional value and zero toxicity. When silica is ingested orally, it passes unchanged through the gastrointestinal (GI) tract, exiting in the feces, leaving no trace behind. Small pieces of silicon dioxide are equally harmless, as long as they are not large enough to mechanically obstruct the GI tract, or jagged enough to lacerate its lining.

A study which followed subjects for 15 years found that higher levels of silica in water appeared to decrease the risk of dementia. The study found that for every 10 milligram-per-day intake of silica in drinking water, the risk of dementia dropped by 11%.<sup>[16]</sup>

## References

- <sup>^</sup> Lynn Townsend White, Jr. (1961). "Eilmer of Malmesbury, an Eleventh Century Aviator: A Case Study of Technological Innovation, Its Context and Tradition". *Technology and Culture* **2** (2): 97–111. doi:10.2307/3101411 (http://dx.doi.org/10.2307%2F3101411) .
- <sup>^ a b c d e f g</sup> Holleman, A. F.; Wiberg, E. (2001), *Inorganic Chemistry*, San Diego: Academic Press, ISBN 0-12-352651-5
- <sup>^ a b c d e f g h i</sup> Greenwood, Norman N.; Earnshaw, A. (1984), *Chemistry of the Elements*, Oxford: Pergamon, pp. 393–99, ISBN 0-08-022057-6
- <sup>^</sup> Wells A.F. (1984). *Structural Inorganic Chemistry*. Oxford Science Publications. ISBN 0-19-855370-6.
- <sup>^</sup> Kirfel, A. (2001). "Electron-density distribution in stishovite, SiO<sub>2</sub>: a new high-energy synchrotron-radiation study". *Acta Crystallographica A* **57**: 663. doi:10.1107/S0108767301010698 (http://dx.doi.org/10.1107%2FS0108767301010698) .
- <sup>^ a b</sup> J. Scherzer (1978). "Dealuminated faujasite-type structures with SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratios over 100". *Journal of Catalysis* **54**: 285. doi:10.1016/0021-9517(78)90051-9 (http://dx.doi.org/10.1016%2F0021-9517%2878%2990051-9) .
- <sup>^</sup> Rosemarie Szostak (1998). *Molecular sieves: Principles of Synthesis and Identification*. Springer. ISBN 0751404802.
- <sup>^</sup> Shell, Scott M.; Pablo G. Debenedetti, Athanassios Z. Panagiotopoulos (2002). "Molecular structural order and anomalies in liquid silica (http://www.engr.ucsb.edu/~shell/papers/2002\_PRE\_silica.pdf)". *Phys. Rev. E* **66**: 011202. doi:10.1103/PhysRevE.66.011202 (http://dx.doi.org/10.1103%2FPhysRevE.66.011202) . http://www.engr.ucsb.edu/~shell/papers/2002\_PRE\_silica.pdf.
- <sup>^ a b c d</sup> Peter Jutzi, Ulrich Schubert (2003). *Silicon chemistry: from the atom to extended systems*. Wiley-VCH. ISBN 3527306471.
- <sup>^ a b</sup> Sunggyu Lee (2006). *Encyclopedia of chemical processing*. CRC Press. ISBN 0824755634.
- <sup>^</sup> Robert Doering, Yoshio Nishi (2007). *Handbook of Semiconductor Manufacturing Technology*. CRC Press. ISBN 1574446754.
- <sup>^</sup> A.B.D. Nandiyanto; S.-G Kim; F. Iskandar; and K. Okuyama (2009). "Synthesis of Silica Nanoparticles with Nanometer-Size Controllable Mesopores and Outer

- Diameters". *Microporous and Mesoporous Materials* **120** (3): 447–453.  
doi:10.1016/j.micromeso.2008.12.019 (http://dx.doi.org/10.1016%2Fj.micromeso.2008.12.019) .
13. ^ Fournier R.O., Rowe J.J. (1977). "The solubility of amorphous silica in water at high temperatures and high pressures". *American Mineralogist* **62**: 1052–1056.
  14. ^ Lidong Wang, D Major, P Paga, D Zhang, M G Norton, D N McIlroy. "High yield synthesis and lithography of silica-based nanospring mats". *Nanotechnology* **17**: S298-S303. doi:10.1088/0957-4484/17/11/S12 (http://dx.doi.org/10.1088%2F0957-4484%2F17%2F11%2FS12) .
  15. ^ "Toxicological Overview of Amorphous Silica in Working Environment (http://www.degussa-nano.de/nano/MCMSbase/Pages/ProvideResource.aspx?respath=/NR/rdonlyres/1E02FAD4-E5D6-4CE2-8E5C-E19F4DAC7838/0/Toxicological\_Overview\_Amorphous\_Silica\_in\_Working\_Environment.pdf) ". http://www.degussa-nano.de/nano/MCMSbase/Pages/ProvideResource.aspx?respath=/NR/rdonlyres/1E02FAD4-E5D6-4CE2-8E5C-E19F4DAC7838/0/Toxicological\_Overview\_Amorphous\_Silica\_in\_Working\_Environment.pdf.
  16. ^ Rondeau, V; Jacqmin-Gadda, H; Commenges, D; Helmer, C; Dartigues, Jf (2009). "Aluminum and silica in drinking water and the risk of Alzheimer's disease or cognitive decline: findings from 15-year follow-up of the PAQUID cohort.". *American journal of epidemiology* **169** (4): 489–96. doi:10.1093/aje/kwn348 (http://dx.doi.org/10.1093%2Faje%2Fkwn348) . PMID 19064650.

## Further reading



- R. K. Iler, *The Chemistry of Silica* (ISBN 0-471-02404-X)

## See also

- Sol-gel
- Physics of glass
- Glass transition
- Amorphous carbonia
- Fused silica
- Silicon carbide
- Mesoporous silica
- Diatomaceous earth - mined fossil diatoms, mostly silica, with many of the same uses as pure silica

## External links

- Tridymite, International Chemical Safety Card 0807 (http://www.inchem.org/documents/icsc/icsc/eics0807.htm)
- Quartz, International Chemical Safety Card 0808 (http://www.inchem.org/documents/icsc/icsc/eics0808.htm)
- Cristobalite, International Chemical Safety Card 0809 (http://www.inchem.org/documents/icsc/icsc/eics0809.htm)
- amorphous, NIOSH Pocket Guide to Chemical Hazards (http://www.cdc.gov/niosh/npg/npgd0552.html)
- crystalline, as respirable dust, NIOSH Pocket Guide to Chemical Hazards (http://www.cdc.gov/niosh/npg/npgd0553.html)
- Formation of silicon oxide layers in the semiconductor industry. (http://www.crystec.com/kiloxide.htm) LPCVD and PECVD method in comparison. Stress prevention.
- Quartz SiO<sub>2</sub> piezoelectric properties (http://www.piezomaterials.com/Quartz-SiO2.htm)
- Silica(SiO<sub>2</sub>) (http://water-chemistry.blogspot.com/2008/08/silica-sio2.html)

-  Media related to Silicon dioxide at Wikimedia Commons
-  "silica". *Encyclopædia Britannica* (11th ed.). 1911.

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Categories: Silicon compounds | Oxides | Ceramic materials | Refractory materials | IARC Group 1 carcinogens | Common oxide glass components | Excipients

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# Zirconium dioxide

From Wikipedia, the free encyclopedia

**Zirconium dioxide** (ZrO<sub>2</sub>), sometimes known as **zirconia**, is a white crystalline oxide of zirconium. Its most naturally occurring form, with a monoclinic crystalline structure, is the rare mineral, baddeleyite. The high temperature cubic crystalline form, called 'cubic zirconia', is rarely found in nature as mineral tazheranite (Zr,Ti,Ca)O<sub>2</sub> (and a doubtful mineral arkelite), but is synthesized in various colours for use as a gemstone. The cubic crystal structured variety cubic zirconia is the best-known diamond simulant.

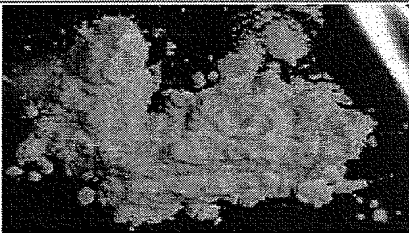
## Contents

- 1 Engineering properties
- 2 Diamond simulant
- 3 Patents
- 4 See also
- 5 References
- 6 Further reading
- 7 External links

## Engineering properties

Zirconium dioxide is one of the most studied ceramic materials. Pure ZrO<sub>2</sub> has a monoclinic crystal structure at room temperature and transitions to tetragonal and cubic at increasing temperatures. The volume expansion caused by the cubic to tetragonal to monoclinic transformation induces very large stresses, and will cause pure ZrO<sub>2</sub> to crack upon cooling from high temperatures. Several different oxides are added to zirconia to stabilize the tetragonal and/or cubic phases: magnesium oxide (MgO), yttrium oxide, (Y<sub>2</sub>O<sub>3</sub>), calcium oxide (CaO), and cerium(III) oxide (Ce<sub>2</sub>O<sub>3</sub>), amongst others.<sup>[1]</sup>

Zirconia is very useful in its 'stabilized' state. In some cases, the tetragonal phase can be

Zirconium dioxide	
	
IUPAC name	Zirconium dioxide Zirconium(IV) oxide
Other names	Zirconia Baddeleyite
Identifiers	
CAS number	1314-23-4 ✓
Properties	
Molecular formula	ZrO <sub>2</sub>
Molar mass	123.218 g/mol
Appearance	white powder
Density	5.68 g/cm <sup>3</sup>
Melting point	<u>2715 °C</u> ✓
Boiling point	4300 °C
Solubility in water	negligible
Solubility	soluble in HF, and hot HSO <sub>4</sub> , HNO <sub>3</sub> , HCl
Refractive index (n <sub>D</sub> )	2.13
Thermochemistry	
Std enthalpy of formation Δ <sub>f</sub> H <sup>o</sup> <sub>298</sub>	−1080 kJ/mol
Standard molar entropy S <sup>o</sup> <sub>298</sub>	50.3 J K <sup>−1</sup> mol <sup>−1</sup>
Hazards	
MSDS	MSDS ( <a href="http://services.georgiasouthern.edu/ess/msds/Zirxonium%20(IV)%20Oxide.pdf">http://services.georgiasouthern.edu/ess/msds/Zirxonium%20(IV)%20Oxide.pdf</a> )

metastable. If sufficient quantities of the metastable tetragonal phase is present, then an applied stress, magnified by the stress concentration at a crack tip, can cause the tetragonal phase to convert to monoclinic, with the associated volume expansion. This phase transformation can then put the crack into compression, retarding its growth, and enhancing the fracture toughness. This mechanism is known as transformation toughening, and significantly extends the reliability and lifetime of products made with stabilized zirconia.<sup>[2][1]</sup>

A special case of zirconia is that of tetragonal zirconia polycrystalline or TZP, which is indicative of polycrystalline zirconia composed of only the metastable tetragonal phase.

The cubic phase of zirconia also has a very low thermal conductivity, which has led to its use as a thermal barrier coating or TBC in jet and diesel engines to allow operation at higher temperatures. Thermodynamically the higher the operation temperature of an engine, the greater the possible efficiency (see Carnot heat engine). As of 2004, a great deal of research is ongoing to improve the quality and durability of these coatings. It is used as a refractory material, in insulation, abrasives, enamels and ceramic glazes. Stabilized zirconia is used in oxygen sensors and fuel cell membranes because it has the ability to allow oxygen ions to move freely through the crystal structure at high temperatures. This high ionic conductivity (and a low electronic conductivity) makes it one of the most useful electroceramics.

The ZrO<sub>2</sub> band gap is dependent on the phase (cubic, tetragonal, monoclinic, or amorphous) and preparation methods, with typical estimates from 5-7 eV.<sup>[3]</sup>

This material is also used in the manufacture of subframes for the construction of dental restorations such as crowns and bridges, which are then veneered with a conventional feldspathic porcelain.<sup>[4]</sup>

Zirconium dioxide can occur as a white powder which possesses both acidic and basic properties. On account of its infusibility and brilliant luminosity when incandescent, it was used as an ingredient of sticks for limelight.

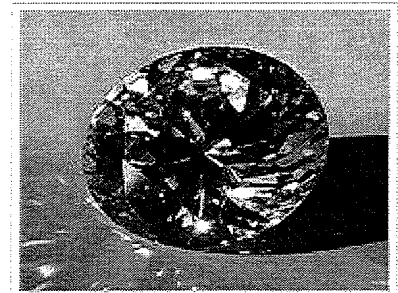
Zirconia is also an important high-k dielectric material that is being investigated for potential applications as an insulator in transistors in future nanoelectronic devices.

## Diamond simulant

*Main article: Cubic zirconia*

EU Index	Not listed
Flash point	Non-flammable
LD <sub>50</sub>	> 8800 mg/kg (oral, rat)
<b>Related compounds</b>	
Other anions	Zirconium disulfide
Other cations	Titanium dioxide Hafnium dioxide
<div>✓ (what is this?) (verify) (<a href="http://en.wikipedia.org/w/index.php?title=Zirconium_dioxide&amp;diff=cur&amp;oldid=269595269">http://en.wikipedia.org/w/index.php?title=Zirconium_dioxide&amp;diff=cur&amp;oldid=269595269</a>)</div> <div>Except where noted otherwise, data are given for materials in their standard state (at 25 °C, 100 kPa)</div>	
Infobox references	

Single crystals of the cubic phase of zirconia are commonly used as diamond simulant in jewelery. Like diamond, cubic zirconia has a cubic crystal structure and a high index of refraction. Discerning a good quality cubic zirconia gem from a diamond is difficult, and most jewellers will have a thermal conductivity tester to identify cubic zirconia by its low thermal conductivity (diamond is a very good thermal conductor). This state of zirconia is commonly called "cubic zirconia," "CZ," or "zircon" by jewellers, but the last name is not chemically accurate. Zircon is actually the mineral name for naturally occurring zirconium silicate ( $\text{ZrSiO}_4$ ). Its transparent form is also used as a gemstone, and its opaque form as a refractory.



Brilliant-cut cubic zirconia

## Patents

On August 7, 2006, Apple Inc. filed a patent for using zirconia oxide ceramics as casing for mobile devices. Some of the current iPods contain radios for built-in Nike+, Bluetooth, or wireless networking. Using zirconia-based ceramics rather than steel or aluminium for its radio transparency characteristics would enable such internal antennae to be within the device, without the need for changes in thickness or a window, like the iPod touch.<sup>[5]</sup>

## See also

- Quenching
- Sintering
- Yttria-stabilized zirconia
- Zirconia fiber insulation
- Transformation toughening

## References

- ↑ <sup>*a b*</sup> Evans, A.G., Cannon, R.M. (1986). "Toughening of brittle solids by martensitic transformations". *Acta Met.* **34**: 761. doi:10.1016/0001-6160(86)90052-0 (http://dx.doi.org/10.1016%2F0001-6160%2886%2990052-0 ).
- ↑ Porter, D.L., Evans, A.G., Heuer, A.H. (1979). "Transformation toughening in PSZ". *Acta Met.* **27**: 1649. doi:10.1016/0001-6160(79)90046-4 (http://dx.doi.org/10.1016%2F0001-6160%2879%2990046-4 ).
- ↑ Chang, Jane P; You-Sheng Lin; Karen Chu (2001). "Rapid thermal chemical vapor deposition of zirconium oxide for metal-oxide-semiconductor field effect transistor application". *Journal of Vacuum Science & Technology B*: **19** (5): 1782–1787. doi:10.1116/1.1396639 (http://dx.doi.org/10.1116%2F1.1396639) .
- ↑ Papaspyridakos, Panos; Kunal Lal (2008). "Complete arch implant rehabilitation using subtractive rapid prototyping and porcelain fused to zirconia prosthesis: A clinical report". *The Journal of Prosthetic Dentistry* **100** (3): 165–172. doi:10.1016/S0022-3913(08)00110-8 (http://dx.doi.org/10.1016%2FS0022-3913%2808%2900110-8) .
- ↑ "Apple seeks patent on radio-transparent zirconia CE casings (http://www.appleinsider.com/article.php?id=2274) ". Apple Insider. 30 November 2006. http://www.appleinsider.com/article.php?id=2274.

## Further reading

- Green, D.J.; Hannink, R.; Swain, M.V. (1989). *Transformation Toughening of Ceramics*. Boca Raton: CRC Press. ISBN 0-8493-6594-5.
- Heuer, A.H., Hobbs, L.W., Eds., *Science and Technology of Zirconia*, Adv. Ceram., Vol. 3, p. 475 (ACerS, Columbus, OH 1981)
- Claussen, N., Rühle, M., Heuer, A.H., *Proc. 2nd Int'l Conf. on Science and Technology of Zirconia*, Adv. Ceram., Vol. 11 (ACerS, Columbus, OH 1984)

## External links

- NIOSH Pocket Guide to Chemical Hazards (<http://www.cdc.gov/niosh/npg/npgd0677.html>)

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Categories: Zirconium compounds | Oxides | Refractory materials | High-k dielectrics | Ceramic materials | Common oxide glass components

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# Aluminium oxide

From Wikipedia, the free encyclopedia

**Aluminium oxide** is an amphoteric oxide of aluminium with the chemical formula  $\text{Al}_2\text{O}_3$ . It is also commonly referred to as **alumina**, corundum, sapphire, ruby or **aloxite**<sup>[3]</sup> in the mining, ceramic and materials science communities. It is produced by the Bayer process from bauxite. Its most significant use is in the production of aluminium metal, although it is also used as an abrasive due to its hardness and as a refractory material due to its high melting point.<sup>[4]</sup>

## Contents

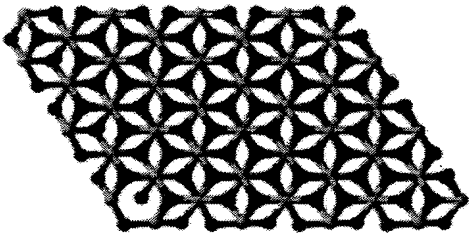
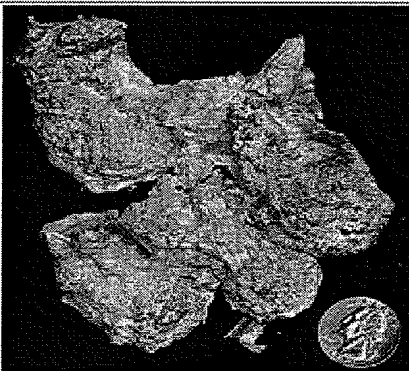
- 1 Natural occurrence
- 2 Properties
- 3 Crystal structure
- 4 Production
- 5 Uses
- 6 See also
- 7 References
- 8 External links

## Natural occurrence

Corundum is the most common naturally-occurring crystalline form of aluminium oxide. Much less-common rubies and sapphires are gem-quality forms of corundum with their characteristic colors due to trace impurities in the corundum structure. Rubies are given their characteristic deep red color and their laser qualities by traces of the metallic element chromium. Sapphires come in different colors given by various other impurities, such as iron and titanium.

## Properties

Aluminium oxide is an electrical insulator but has a relatively high thermal conductivity

Aluminium oxide	
	
	
Identifiers	
CAS number	1344-28-1 ✓
RTECS number	BD120000
ChemSpider ID	14086
Properties	
Molecular formula	$\text{Al}_2\text{O}_3$
Molar mass	101.9613 g/mol
Appearance	white solid
Odor	odorless
Density	3.95-4.1 g/cm <sup>3</sup>
Melting point	<u>2072 °C</u> <sup>[1]</sup> ✓
Boiling point	2980 °C <sup>[2]</sup>
Solubility in water	insoluble
Refractive index ( <i>n</i> <sub>D</sub> )	<i>n</i> <sub>ω</sub> =1.768 - 1.772 <i>n</i> <sub>ε</sub> =1.760 - 1.763 Birefringence 0.008
Structure	
Crystal structure	Trigonal, hR30, SpaceGroup = R-3c, No. 167
Coordination geometry	octahedral
Thermochemistry	



(40 Wm<sup>-1</sup>K<sup>-1</sup>) for a ceramic material. In its most commonly occurring crystalline form, called corundum or α-aluminium oxide, its hardness makes it suitable for use as an abrasive and as a component in cutting tools.<sup>[4]</sup>

Aluminium oxide is responsible for resistance of metallic aluminium to weathering. Metallic aluminium is very reactive with atmospheric oxygen, and a thin passivation layer of alumina (4 nm thickness) forms in about 100 picoseconds on any exposed aluminium surface.<sup>[5]</sup> This layer protects the metal from further oxidation. The thickness and properties of this oxide layer can be enhanced using a process called anodising. A number of alloys, such as aluminium bronzes, exploit this property by including a proportion of aluminium in the alloy to enhance corrosion resistance. The alumina generated by anodising is typically amorphous, but discharge assisted oxidation processes such as plasma electrolytic oxidation result in a significant proportion of crystalline alumina in the coating, enhancing its hardness.

Aluminium oxide was taken off the United States Environmental Protection Agency's chemicals lists in 1988. Aluminium oxide is on EPA's TRI list if it is a fibrous form.<sup>[6]</sup>

Crystal structure

The most common form of crystalline alumina, α-aluminium oxide, is known as corundum. When trace elements make it appear red it is known as ruby, but all other colorations fall under the designation sapphire. Corundum has a trigonal Bravais lattice with a space group of R-3c (number 167 in the International Tables). The primitive cell contains two formula units of aluminium oxide. The oxygen ions nearly form a hexagonal close-packed structure with aluminium ions filling two-thirds of the octahedral interstices. Alumina also exists in other phases, namely η, χ, γ, δ and θ theta aluminas.<sup>[7]</sup> Each has a unique crystal structure and properties. The so-called β-alumina proved to be NaAl<sub>11</sub>O<sub>17</sub>.<sup>[8]</sup>

Production

Aluminium hydroxide minerals are the main component of bauxite, the principal ore of aluminium. The bauxite ore is made up of a mixture of the minerals gibbsite (Al(OH)<sub>3</sub>), boehmite (γ-AlO(OH)), and diaspora (α-AlO(OH)) along with iron oxides and hydroxides, quartz and clay minerals.<sup>[9]</sup>

Std enthalpy of formation Δ <sub>f</sub> <i>H</i> <sup>∘</sup> <sub>298</sub>	−1675.7 kJ⋅mol <sup>−1</sup>
Standard molar entropy <i>S</i> <sup>∘</sup> <sub>298</sub>	50.92 J⋅mol <sup>−1</sup> ⋅K <sup>−1</sup>
<b>Hazards</b>	
MSDS	External MSDS
EU classification	Not listed.
NFPA 704	<div><div><div><div><div><div></div></div></div><div><div><div></div></div></div><div><div><div></div></div></div></div><div><div><div></div></div></div><div><div><div></div></div></div></div></div>

Bauxite is purified by the Bayer process:



The other components of bauxite do not dissolve. The  $\text{SiO}_2$  dissolves as silicate  $\text{Si}(\text{OH})_6^{2-}$ . Upon filtering,  $\text{Fe}_2\text{O}_3$  is removed. When the Bayer liquor is cooled,  $\text{Al}(\text{OH})_3$  precipitates, leaving the silicates in solution. The mixture is then calcined (heated strongly) to give aluminium oxide:<sup>[4]</sup>



The formed  $\text{Al}_2\text{O}_3$  is alumina. The alumina formed tends to be multi-phase; i.e., constituting several of the alumina phases rather than solely corundum.<sup>[7]</sup> The production process can therefore be optimized to produce a tailored product. The type of phases present affects, for example, the solubility and pore structure of the alumina product which, in turn, affects the cost of aluminium production and pollution control.<sup>[7]</sup>

## Uses

Annual world production of alumina is approximately 45 million tonnes, over 90% of which is used in the manufacture of aluminium metal.<sup>[4]</sup> The major uses of specialty aluminium oxides are in refractories, ceramics, and polishing and abrasive applications. Large tonnages are also used in the manufacture of zeolites, coating titania pigments, and as a fire retardant/smoke suppressant.

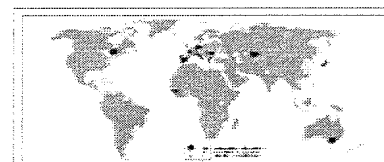
Alumina is a medium for chemical chromatography, available in basic (pH 9.5), acidic (pH 4.5 when in water) and neutral formulations.

In lighting, GE developed "Lucalox" in 1961,<sup>[10]</sup> a transparent alumina used in sodium vapor lamps. Aluminium oxide is also used in preparation of coating suspensions in compact fluorescent lamps.

Health and medical applications include it as a material in hip replacements.<sup>[4]</sup> It is used in water filters (derived water treatment chemicals such as aluminium sulfate, aluminium chlorohydrate and sodium aluminate, are one of the few methods available to filter water-soluble fluorides out of water). It is also used in toothpaste formulations.

Aluminium oxide is used for its hardness and strength. Most pre-finished wood flooring now uses aluminium oxide as a hard protective coating. In 2004, 3M developed a technique for making a ceramic composed of aluminium oxide and rare earth elements to produce a strong glass called transparent alumina. Alumina can be grown as a coating on aluminium by anodising or by plasma electrolytic oxidation (*see the "Properties" section, above*). Both its strength and abrasive characteristics are due to aluminium oxide's great hardness (position 9 on the Mohs scale of mineral hardness).

It is widely used as a coarse or fine abrasive, including as a much less expensive substitute for industrial diamond. Many types of sandpaper use aluminium oxide crystals. In addition, its low heat retention and low specific heat make it widely used in grinding operations, particularly cutoff tools. As the powdery abrasive mineral aloxite, it is a major component, along with silica, of the cue tip "chalk" used in billiards. Aluminium oxide powder is used in some CD/DVD polishing and scratch-repair kits. Its polishing qualities are also behind its use in toothpaste.



Alumina output in 2005

Aluminium oxide is widely used in the fabrication of superconducting devices, particularly single electron transistors and superconducting quantum interference devices (SQUID), where it is used to form highly resistive quantum tunneling barriers.

## See also

- Bayer process
- List of alumina refineries
- Micro-Pulling-Down
- Transparent alumina
- Ruby
- Sapphire
- Corundum

## References

1. <sup>^</sup> P. Patnaik (2002). *Handbook of Inorganic Chemicals*. McGraw-Hill. ISBN 0070494398.
2. <sup>^</sup> Mallinckrodt Baker, MSDS. "Aluminum Oxide: Material Safety Data Sheet (A28440) (<http://www.jtbaker.com/msds/englishhtml/a2844.htm>) ". <http://www.jtbaker.com/msds/englishhtml/a2844.htm>.
3. <sup>^</sup> "Aloxite (<http://www.chemindustry.com/chemicals/14835.html>) ". ChemIndustry.com database. <http://www.chemindustry.com/chemicals/14835.html>. Retrieved 24 February 2007.
4. <sup>^</sup> <sup>a</sup> <sup>b</sup> <sup>c</sup> <sup>d</sup> <sup>e</sup> "Alumina (Aluminium Oxide) – The Different Types of Commercially Available Grades (<http://www.azom.com/details.asp?ArticleID=1389>) ". The A to Z of Materials. <http://www.azom.com/details.asp?ArticleID=1389>. Retrieved 2007-10-27.
5. <sup>^</sup> Campbell, Timothy (1999). "Dynamics of Oxidation of Aluminum Nanoclusters using Variable Charge Molecular-Dynamics Simulations on Parallel Computers (<http://cacs.usc.edu/papers/Campbell-nAloxid-PRL99.pdf>) ". *Physical Review Letters* **82**: 4866. doi:10.1103/PhysRevLett.82.4866 (<http://dx.doi.org/10.1103/2FPhysRevLett.82.4866>) . <http://cacs.usc.edu/papers/Campbell-nAloxid-PRL99.pdf>.
6. <sup>^</sup> "EPCRA Section 313 Chemical List For Reporting Year 2006 (<http://www.epa.gov/tri/chemical/chemical%20lists/RY2006ChemicalList.pdf>) " (PDF). US EPA. <http://www.epa.gov/tri/chemical/chemical%20lists/RY2006ChemicalList.pdf>. Retrieved 2008-09-30.
7. <sup>^</sup> <sup>a</sup> <sup>b</sup> <sup>c</sup> G. Paglia (2004). "Determination of the Structure of γ-Alumina using Empirical and First Principles Calculations Combined with Supporting Experiments (<http://espace.library.curtin.edu.au/R?func=search-simple-go&ADJACENT=Y&REQUEST=adt-WCU20040621.123301>) " (free download). Curtin University of Technology, Perth. <http://espace.library.curtin.edu.au/R?func=search-simple-go&ADJACENT=Y&REQUEST=adt-WCU20040621.123301>. Retrieved 2009-05-05.
8. <sup>^</sup> E. Wiberg and A. F. Holleman (2001). *Inorganic Chemistry*. Elsevier. ISBN 0123526515.
9. <sup>^</sup> "Bauxite and Alumina Statistics and Information (<http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/>) ". USGS. <http://minerals.usgs.gov/minerals/pubs/commodity/bauxite/>. Retrieved 2009-05-05.

10. ^ "GE Innovation Timeline 1957-1970 (http://www.ge.com/innovation/timeline/eras/science\_and\_research.html) ".

[http://www.ge.com/innovation/timeline/eras/science\\_and\\_research.html](http://www.ge.com/innovation/timeline/eras/science_and_research.html). Retrieved 2009-01-12.

## External links

- International Chemical Safety Card 0351 ([http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/\\_icsc03/icsc0351.htm](http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/_icsc03/icsc0351.htm))

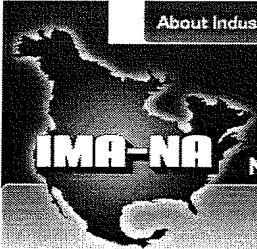
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## Talc

### What is Talc?

*Talc is the world's softest mineral. Although all talc ores are soft, platy, water repellent and chemically inert, no two talcs are quite the same. Talc is a vital part of everyday life. The magazines we read, the polymers in our cars and houses, the paints we use and the tiles we walk on are just some of the products that talc enhances.*



Talc is a hydrated magnesium sheet silicate with the chemical formula  $Mg_3Si_4O_{10}(OH)_2$ . The elementary sheet is composed of a layer of magnesium-oxygen/hydroxyl octahedra, sandwiched between two layers of siliconoxygen tetrahedra. The main or basal surfaces of this elementary sheet do not contain hydroxyl groups or active ions, which explains talc's hydrophobicity and inertness.

Talc is practically insoluble in water and in weak acids and alkalis. It is neither explosive nor flammable. Although it has very little chemical reactivity, talc does have a marked affinity for certain organic chemicals, i.e. it is organophilic. Above 900°C, talc progressively loses its hydroxyl groups and above 1050°C, it re-crystallizes into different forms of enstatite (anhydrous magnesium silicate). Talc's melting point is at 1500°C.

### Morphology

The size of an individual talc platelet (= a few thousand elementary sheets) can vary from approximately 1 micron to over 100 microns depending on the deposit. It is this individual platelet size that determines a talc's platyness or lamellarity. A highly lamellar talc has large individual platelets whereas a microcrystalline talc's platelets are much smaller. The elementary sheets are stacked on top of one another, like flaky pastry, and, because the binding forces (known as Van der Waal's forces) linking one elementary sheet to its neighbors are very weak, the platelets slide apart at the slightest touch, giving talc its characteristic softness.

### Related minerals

Talc ores also differ according to their mineralogical composition (i.e. the type and proportion of associated minerals present). They can be divided into two main types of deposits: talc-chlorite and talc-carbonate. Talc-chlorite ore bodies consist mainly of talc (sometimes 100%) and chlorite, which is hydrated magnesium and aluminium silicate. Chlorite is lamellar, soft and organophilic like talc. It is however more hydrophilic. Talc-carbonate ore bodies are mainly composed of talc carbonate and traces of chlorite. Carbonate is typically magnesite (magnesium carbonate) or dolomite (magnesium and calcium carbonate). Talc - carbonate ores are processed to removed associated minerals and to produce pure talc concentrate. Talc's properties (platyness, softness, hydro-phobicity, organophilicity, inertness and mineralogical composition) provide specific functions in many industries.

**Agriculture and Food:** Talc is an effective anti-caking agent, dispersing agent and die lubricant and therefore helps animal feed and fertilizer plants to function more efficiently. In premixes and agricultural chemicals, it makes an ideal inert carrier. Talc also is used as an anti-stick coating agent in a number of popular foods including chewing gum, boiled sweets, cured meats, and for rice polishing. In olive oil production, as a processing aid, it increases yield and improves the clarity of the oil.



**Ceramics:** Talc is a phyllosilicate which imparts a wide range of functions to floor and wall tiles and sanitaryware, tableware, refractories and technical ceramics. In traditional building ceramics (tiles and sanitaryware), it is used essentially as a flux, enabling firing temperatures and cycles to be reduced. In refractory applications, chlorite-rich talc is transformed into cordierite to improve thermal shock resistance. For steatite ceramics, talcs with a microcrystalline are the most appropriate. During firing, the talc is transformed into enstatite, which possesses electro-insulating properties. As for very low iron content talcs, they are particularly suitable for use in frit, engobe and glaze compositions.

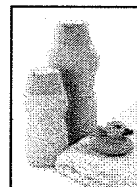
**Coatings:** Talc confers a whole range of benefits to coatings. In interior and exterior decorative paints, they act as extenders to improve hiding power and titanium dioxide efficiency. Talc's lamellar platelets make paint easier to apply and improve cracking resistance and sagging. They also enhance matting. In anti-corrosion primers, talc is used to improve corrosion resistance and paint adhesion. Talc also brings benefits to inks, jointing compounds, putties and adhesives.



**Paper:** Talc is used in both uncoated and coated rotogravure papers where it improves printability as well as reducing surface friction, giving substantial improvements in productivity at the paper mill and print house. It also improves mattness and reduce ink scuff in offset papers. Used as pitch control agents, talc "cleans" the papermaking process by adsorbing any sticky resinous particles in the pulp onto their platy surfaces, thereby preventing the agglomeration and deposition of these on the felts and calendars. As opposed to chemical pitch-control products that pollute the process water, talc is removed together with the pulp, enabling the papermaker to operate more easily in closed-circuit. In specialty papers such as colored papers or labels, talc helps to improve quality and productivity.



**Personal Care:** As it is soft to the touch and inert, talc has been valued for centuries as a body powder. Today it also plays an important role in many cosmetic products, providing the silkiness in blushes, powder compacts and eye shadows, the transparency of foundations and the sheen of beauty creams. In pharmaceuticals, talc is an ideal excipient, used as a glidant, lubricant and diluent. Soap manufacturers also use talc to enhance skin care performance.

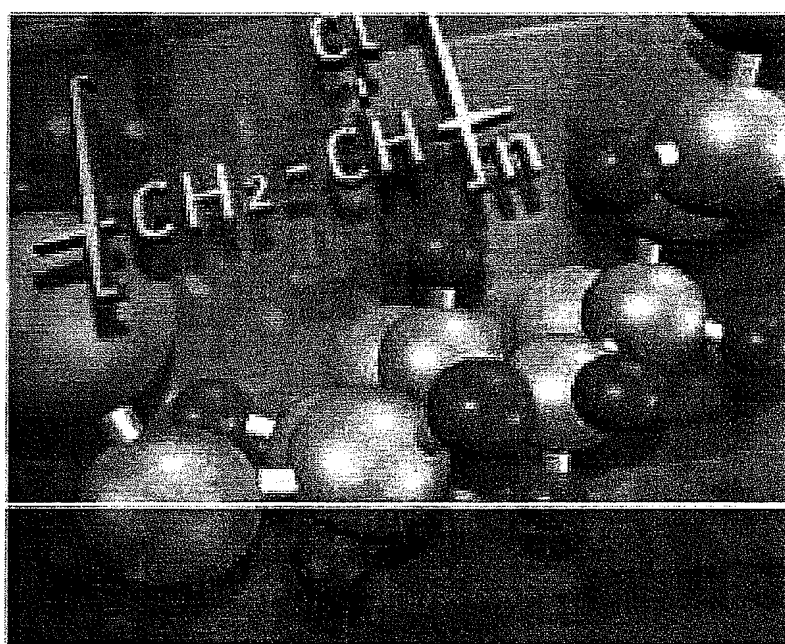


**Plastics:** Talc imparts a variety of benefits to polypropylene, for instance higher stiffness and improved dimensional stability. In automotive parts (under-the-hood, dashboard, bumper interiors and exterior trim), household appliances and white goods. It requires advanced milling technology to obtain the finest talc without diminishing the reinforcing power of its lamellar structure. Talc also is used for linear low density polyethylene (LLDPE) antiblocking and as a nucleating agent in semicrystalline polymers. In polypropylene food packaging applications, talc is a highly effective reinforcing filler.

**Rubber:** Talc reduces the viscosity of rubber compounds, thereby facilitating the processing of moulded parts. It

Charles E. Wilkes  
James W. Summers  
Charles A. Daniels (Eds.)

# PVC Handbook



HANSER

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**Table 12.7** Miscellaneous PVC Properties

PVC property	Values			References
Crystallographic data				
Orthorhombic, 2 mers/cell, Syndiotactic PVC	a	b	c	
• Commercial PVC	1.06 nm	0.54 nm	0.51 nm	44
• Single crystal	1.024 nm	0.524 nm	0.508 nm	17
Crystallinity				
• Commercial – as polymerized	19%			45
• Commercial – from melt	4.9%			
Average crystal size				
• Chain direction	0.7 nm (3 mer)			46
• Perpendicular to chain	4.1 nm, 4.1 nm			
Crystallite spacing	10 nm (0.01 μm)			46
Melting point	100–260 °C (very broad)			47
Gelation (fusion)				
unplasticized PVC – start	160–170 °C			47
Density (uncompounded)				
• Whole	1.39 g/cc			48
• Crystallites	1.53 g/cc			17
Refractive index	1.54			49
Entanglement molecular weight	5, 410			50
Glass transition temperature $T_g$ , unplasticized PVC	82 °C			
Poisson's ratio, unplasticized	0.41			
Solubility parameter	9.9 (cal/cm <sup>3</sup> ) <sup>1/2</sup> , 20.2 MPa <sup>1/2</sup>			51
Coefficient of linear thermal expansion, unplasticized				
	7 × 10 <sup>-5</sup> /°C			26
Specific heat, unplasticized PVC				
	23 °C	0.92 J/g °C		52
	50 °C	1.05 J/g °C		
	80 °C	1.45 J/g °C		
	120 °C	1.63 J/g °C		
with 50 phr DOP				
	23 °C	1.54 J/g °C		
	50 °C	1.67 J/g °C		
	80 °C	1.75 J/g °C		
	120 °C	1.88 J/g °C		
Thermal conductivity, unplasticized				
	17.5 × 10 <sup>-4</sup> J/cm s °C			53
Dielectric constant, 25 °C, 1 kHz	3.39			26
Dielectric strength, unplasticized	20 kV/mm			
Heat of combustion, unplasticized	-19,000 kJ/kg			26
Ignition temperature, unplasticiz.				
• flash-ignition	391 °C			54
• self-ignition	454 °C			
Heat of polymerization	-96 to -109 kJ/mol			26



# Polyvinyl chloride

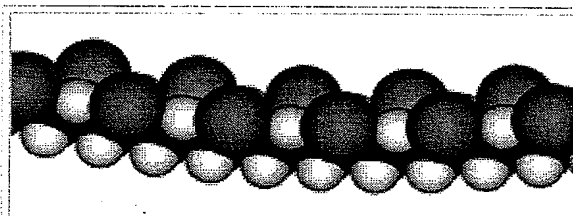
From Wikipedia, the free encyclopedia

**Polyvinyl chloride**, (IUPAC **Poly(chloroethanediyl)**) commonly abbreviated **PVC**, is the third most widely used thermoplastic polymer after polyethylene and polypropylene. In terms of revenue generated, it is one of the most valuable products of the chemical industry. Around the world, over 50% of PVC manufactured is used in construction. As a building material, PVC is cheap, durable, and easy to assemble. The PVC world market grew with an average rate of approximately 5% in the last years and will probably reach a volume of 40 million tons by the year 2016.

It can be made softer and more flexible by the addition of plasticizers, the most widely-used being phthalates. In this form, it is used in clothing and upholstery, and to make flexible hoses and tubing, flooring, to roofing membranes, and electrical cable insulation. It is also commonly used in figurines and in inflatable products such as waterbeds, pool toys, and inflatable structures.

## Polyvinyl chloride

Density	1390 kg/m <sup>3</sup> <sup>[1]</sup>
Young's modulus ( <i>E</i> )	2900-3300 MPa
Tensile strength( $\sigma_t$ )	50-80 MPa
Elongation at break	20-40%
Notch test	2-5 kJ/m <sup>2</sup>
Glass temperature	82 °C <sup>[1]</sup>
Melting point	100–260 °C <sup>[1]</sup> ✓
Vicat B	85 °C <sup>[2]</sup>
Heat transfer coefficient ( $\lambda$ )	0.16 W/(m·K)
Effective heat of combustion	17.95 MJ/kg
Linear expansion coefficient ( $\alpha$ )	8 · 10 <sup>-5</sup> /K
Specific heat ( <i>c</i> )	0.9 kJ/(kg·K)
Water absorption (ASTM)	0.04-0.4
Price	0.5-1.25 €/kg



Polyvinyl chloride

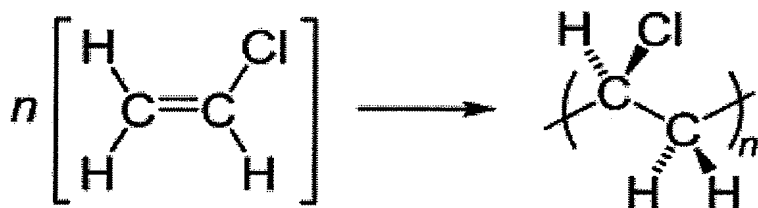
## Contents

- 1 Preparation
- 2 History
- 3 Applications
  - 3.1 Clothing
  - 3.2 Electric wires
  - 3.3 Pipes
  - 3.4 Portable electronic accessories
  - 3.5 Signs
  - 3.6 Joining
  - 3.7 Ceiling tiles
  - 3.8 Unplasticized polyvinyl chloride (uPVC)
- 4 Health and safety
  - 4.1 Phthalate plasticizers
  - 4.2 Vinyl chloride monomer

- 4.3 Dioxins
- 4.4 Bans
- 5 Recycling
- 6 See also
- 7 References
  - 7.1 Notes
  - 7.2 Bibliography
- 8 Movies
- 9 External links

## Preparation

Polyvinyl chloride is produced by polymerization of the vinyl chloride monomer (VCM), as shown. Since about 57% of its mass is chlorine, creating a given mass of PVC requires less petroleum than many other polymers.



By far the most widely used production process is suspension polymerization. In this process, VCM and water are introduced into the polymerization reactor and a polymerization initiator, along with other chemical additives, are added to initiate the polymerization reaction. The contents of the reaction vessel are continually mixed to maintain the suspension and ensure a uniform particle size of the PVC resin. The reaction is exothermic, and thus requires a cooling mechanism to maintain the reactor contents at the appropriate temperature. As the volumes also contract during the reaction (PVC is denser than VCM), water is continually added to the mixture to maintain the suspension.

Once the reaction has run its course, the resulting PVC slurry is degassed and stripped to remove excess VCM (which is recycled into the next batch) then passed through a centrifuge to remove most of the excess water. The slurry is then dried further in a hot air bed and the resulting powder sieved before storage or pelletization. In normal operations, the resulting PVC has a VCM content of less than 1 part per million.

Other production processes, such as micro-suspension polymerization and emulsion polymerization, produce PVC with smaller particle sizes (10µm vs 120-150µm for suspension PVC) with slightly different properties and with somewhat different sets of applications.

The product of the polymerization process is unmodified PVC. Before PVC can be made into finished products, it almost always requires conversion into a compound by the incorporation of additives such as heat stabilizers, UV stabilizers, lubricants, plasticizers, processing aids, impact modifiers, thermal modifiers, fillers, flame retardants, biocides, blowing agents and smoke suppressors, and, optionally pigments.<sup>[3]</sup>

## History

PVC was accidentally discovered at least twice in the 19th century, first in 1835 by Henri Victor Regnault and in 1872 by Eugen Baumann. On both occasions the polymer appeared as a white solid inside flasks of vinyl chloride that had been left exposed to sunlight. In the early 20th century the Russian chemist Ivan Ostromislensky and Fritz Klatte of the German chemical company Griesheim-Elektron both attempted to use PVC (polyvinyl chloride) in commercial products, but difficulties in processing the rigid, sometimes brittle polymer blocked their efforts. Waldo Semon and the B.F. Goodrich Company developed a method in 1926 to plasticize PVC by blending it with various additives. The result was a more flexible and more easily-processed material that soon achieved widespread commercial use.

## Applications

PVC's intrinsic properties make it suitable for a wide variety of applications. It is biologically and chemically resistant, making it the plastic of choice for most household sewerage pipes and other pipe applications where corrosion would limit the use of metal.

With the addition of impact modifiers and stabilizers, it becomes a popular material for window and door frames. By adding plasticizers, it can become flexible enough to be used in cabling applications as a wire insulator.

### Clothing

PVC has become widely used in clothing, to either create a leather-like material or at times simply for the effect of PVC. PVC clothing is common in Goth, Punk, alternative fashions, and Fetish wear. PVC is cheaper than rubber, leather, and latex and so it is more widely available and worn.

PVC fabric has a sheen to it and is waterproof. It is commonly used in coats, jackets, aprons, and bags because of this.

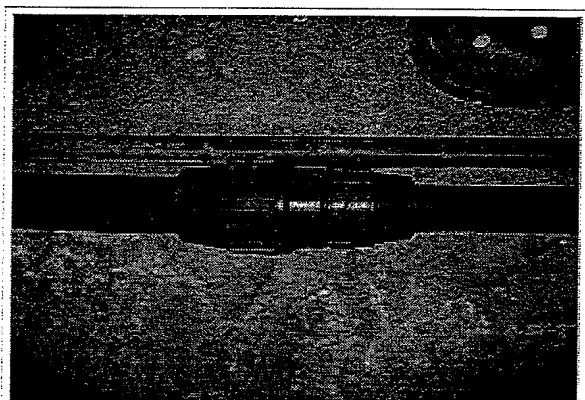
### Electric wires

PVC is commonly used as the insulation on electric wires; the plastic used for this purpose needs to be plasticized.

In a fire, PVC-coated wires can form HCl fumes; the chlorine serves to scavenge free radicals and is the source of the material's fire retardance. While HCl fumes can also pose a health hazard in their own right, HCl dissolves in moisture and breaks down onto surfaces, particularly in areas where the air is cool enough to breathe, and is not available for inhalation.<sup>[4]</sup> Frequently in applications where smoke is a major hazard (notably in tunnels) PVC-free LSOH (low-smoke, zero-halogen) cable insulation is preferred.

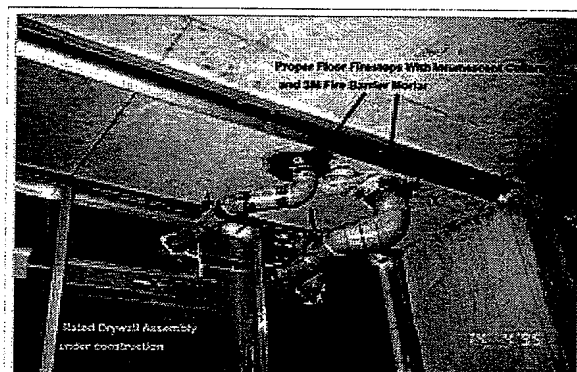
### Pipes

Roughly half of the world's polyvinyl chloride resin manufactured annually is used for producing pipes for various municipal and industrial applications.<sup>[5]</sup> In the water distribution market it accounts for 66 percent of the market in the US, and in sanitary sewer pipe applications, it accounts for 75 percent.<sup>[6]</sup> Its light weight, high strength, and low reactivity make it particularly well-suited to this purpose. In addition, PVC pipes can be fused together using various solvent cements, or heat-fused (butt-fusion process, similar to joining HDPE pipe), creating permanent joints that are virtually impervious to leakage.



PVC pipes inside of a water mine, the top one is 20mm drinking water quality and the bottom is for irrigation, with connectors from 48mm to 32mm pipe

In



Nortown Casitas, North York (now Toronto), Ontario, Canada, April 1995: Set up for subsequent code infraction in plastic pipe wall penetrations: improper hole sizing. Firestops (in the walls) the plumber considered to be the drywall's responsibility. Floor openings are properly done in this case, with intumescent pipe collars and firestop mortar. The intumescent will expand and choke off the missing pipes. Drywall mud does not work as a plastic pipe firestop in the wall.

PVC pipes in use with intumescent firestops at Nortown Casitas, North York, Ontario.

February, 2007 the California Building Standards Code was updated to approve the use of chlorinated polyvinyl chloride (CPVC) pipe for use in residential water supply piping systems. CPVC has been a nationally-accepted material in the US since 1982; California, however, has permitted only limited use since 2001. The Department of Housing and Community Development prepared and certified an Environmental Impact Report resulting in a recommendation that the Commission adopt and approve the use of CPVC. The Commission's vote was unanimous and CPVC has been placed in the 2007 California Plumbing Code.<sup>[7]</sup>

In the United States and Canada, PVC pipes account for the largest majority of pipe materials used in buried municipal applications for drinking water distribution and wastewater mains. A detailed State-of-the-Art review of PVC pipes in North America can be found in an article titled Thermoplastics at Work: A Comprehensive Review of Municipal PVC Piping Products.<sup>[8]</sup>

## Portable electronic accessories

PVC is finding increased use as a composite for the production of accessories or housings for portable electronics. Through a fusing process, it can adopt cleaning properties possessed by materials such as wool or cotton which can absorb dust particles and bacteria. Its inherent ability to absorb particles from the LCD screen and its form fitting characteristics make it effective.

## Signs

Polyvinyl chloride is formed in flat sheets in a variety of thicknesses and colors. As flat sheets, PVC is often expanded to create voids in the interior of the material, providing additional thickness without additional weight and cost. Sheets are cut using saw and rotary

cutting equipment. Plasticized PVC is also used to produce thin, colored, or clear, adhesive-backed films referred to simply as vinyl. These films are typically cut on a computer-controlled plotter or printed in a wide-format printer. These sheets and films are used to produce a wide variety of commercial signage products and markings on vehicles.

## Joining

PVC Cements are available at plumbing supply houses. The cement softens the material to a gel state until the adhesive layer cures. This has another practical application of being able to hand-machine with a razor blade the PVC pipe to change the wall thickness to allow assembly of nonstandard radius arc segments of electrical conduit large radius elbows.

## Ceiling tiles

PVC Ceiling Tiles are tin alternative ceiling tiles that are easy to install over any flat surface. They can be glued onto an existing ceiling with a reasonably flat surface.

## Unplasticized polyvinyl chloride (uPVC)

uPVC or Rigid PVC is often used in the building industry as a low-maintenance material, particularly in Ireland and the UK, and in the United States where it is known as vinyl, or vinyl siding.<sup>[9][10]</sup> The material comes in a range of colors and finishes, including a photo-effect wood finish, and is used as a substitute for painted wood, mostly for window frames and sills when installing double glazing in new buildings, or to replace older single glazed windows. It has many other uses including fascia, and siding or weatherboarding. The same material has almost entirely replaced the use of cast iron for plumbing and drainage, being used for waste pipes, drainpipes, gutters and downpipes.<sup>[11]</sup>



Modern "Tudorbethan" house with uPVC gutters and downpipes, fascia, decorative imitation "half-timbering", windows, and doors

Due to environmental concerns use of PVC is discouraged by some local authorities in countries such as Germany and The Netherlands.<sup>[12][13]</sup> This concerns both flexible PVC and rigid uPVC as not only the plasticizers in PVC are seen as a problem but also the emissions from manufacturing and disposal. The use of modern impact modifiers offer great stability. The issues of migration and brittleness of the PVC compound are overcome.

## Health and safety

### Phthalate plasticizers

Many vinyl products contain additional chemicals to change the chemical consistency of the product. Some of these additional chemicals called additives can leach out of vinyl products. Plasticizers that must be added to make PVC flexible have been an additive of particular concern.

Because soft PVC toys have been made for babies for years, there are concerns that these additives leach out of soft toys into the mouths of the children chewing on them. Phthalates

mimic human hormones and also affect various life forms including fish and invertebrates adversely. Additionally, adult sex toys have been demonstrated to contain high concentrations of the additives.<sup>[14]</sup> In January 2006, the European Union placed a ban on six types of phthalate softeners, including DEHP (diethylhexyl phthalate), used in toys.<sup>[15]</sup> In the U.S. most companies have voluntarily stopped manufacturing PVC toys with DEHP and in 2003 the US Consumer Product Safety Commission (CPSC) denied a petition for a ban on PVC toys made with an alternative plasticizer, DINP (diisononyl phthalate).<sup>[16]</sup> In April 2006, the European Chemicals Bureau of the European Commission published an assessment of DINP which found risk "unlikely" for children and newborns.<sup>[17]</sup>

Vinyl IV bags used in neo-natal intensive care units have also been shown to leach DEHP. In a draft guidance paper published in September 2002, the US FDA recognizes that many medical devices with PVC containing DEHP are not used in ways that result in significant human exposure to the chemical.<sup>[1]</sup> (<http://www.fda.gov/OHRMS/DOCKETS/98fr/090602b.htm>) The FDA, however, suggests that manufacturers consider eliminating DEHP in certain devices that can result in high aggregate exposures for sensitive patient populations such as neonates.

Other vinyl products including car interiors, shower curtains, and flooring initially release chemical gases into the air. Some studies indicate that this outgassing of additives may contribute to health complications, and have resulted in a call for banning the use of DEHP on shower curtains, among other uses.<sup>[18]</sup> The Japanese car companies Toyota, Nissan, and Honda have eliminated PVC in their car interiors starting in 2007.

In 2004 a joint Swedish-Danish research team found a statistical association between allergies in children and indoor air levels of DEHP and BBzP (butyl benzyl phthalate), which is used in vinyl flooring.<sup>[19]</sup> In December 2006, the European Chemicals Bureau of the European Commission released a final draft risk assessment of BBzP which found "no concern" for consumer exposure including exposure to children.<sup>[20]</sup>

In November, 2005 one of the largest hospital networks in the U.S., Catholic Healthcare West, signed a contract with B.Braun for vinyl-free intravenous bags and tubing.<sup>[21]</sup> According to the Center for Health, Environment & Justice (<http://www.chej.org>) in Falls Church, VA, which helps to coordinate a "precautionary" "PVC Campaign" (<http://www.besafenet.com/pvc>) ", several major corporations including Microsoft, Wal-Mart, and Kaiser Permanente announced efforts to eliminate PVC ([http://www.besafenet.com/pvc/newsreleases/microsoft\\_news\\_release.htm](http://www.besafenet.com/pvc/newsreleases/microsoft_news_release.htm)) from products and packaging in 2005. Target is reducing its sale of items with PVC. ([http://besafenet.com/pvc/newsreleases/target\\_to\\_reduce\\_use.htm](http://besafenet.com/pvc/newsreleases/target_to_reduce_use.htm))

The FDA Paper titled "Safety Assessment of Di(2-ethylhexyl)phthalate (DEHP) Released from PVC Medical Devices" states that [3.2.1.3] Critically ill or injured patients may be at increased risk of developing adverse health effects from DEHP, not only by virtue of increased exposure, relative to the general population, but also because of the physiological and pharmacodynamic changes that occur in these patients, compared to healthy individuals.<sup>[22]</sup>

In 2008 the European Union's Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) reviewed the safety of DEHP in medical devices. The SCENIHR report ([http://ec.europa.eu/health/ph\\_risk/committees/04\\_scenihr/docs/scenihr\\_o\\_014.pdf](http://ec.europa.eu/health/ph_risk/committees/04_scenihr/docs/scenihr_o_014.pdf)) states

that certain medical procedures used in high risk patients result in a significant exposure to DEHP and concludes there is still a reason for having some concerns about the exposure of prematurely born male babies to medical devices containing DEHP. The Committee said there are some alternative plasticisers available for which there is sufficient toxicological data to indicate a lower hazard compared to DEHP but added that the functionality of these plasticisers should be assessed before they can be used as an alternative for DEHP in PVC medical devices.

## Vinyl chloride monomer

In the early 1970s, Dr. John Creech and Dr. Maurice Johnson were the first to clearly link and recognize the carcinogenicity of vinyl chloride monomer to humans when workers in the polyvinyl chloride polymerization section of a B.F. Goodrich plant near Louisville, Kentucky, were diagnosed with liver angiosarcoma also known as hemangiosarcoma, a rare disease.<sup>[23]</sup> Since that time, studies of PVC workers in Australia, Italy, Germany, and the UK have all associated certain types of occupational cancers with exposure to vinyl chloride. The link between angiosarcoma of the liver and long-term exposure to vinyl chloride is the only one that has been confirmed by the International Agency for Research on Cancer. All the cases of angiosarcoma developed from exposure to vinyl chloride monomer, were in workers who were exposed to very high VCM levels, routinely, for many years. These workers cleaned accretions in reactors, a practice that has now been replaced by automated high pressure water jets.

A 1997 U.S. Centers for Disease Control and Prevention (CDC) report concluded that the development and acceptance by the PVC industry of a closed loop polymerization process in the late 1970s "almost completely eliminated worker exposures" and that "new cases of hepatic angiosarcoma in vinyl chloride polymerization workers have been virtually eliminated."<sup>[24]</sup>

According to the EPA, "vinyl chloride emissions from polyvinyl chloride (PVC), ethylene dichloride (EDC), and vinyl chloride monomer (VCM) plants cause or contribute to air pollution that may reasonably be anticipated to result in an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness. Vinyl chloride is a known human carcinogen that causes a rare cancer of the liver."<sup>[25]</sup> EPA's 2001 updated Toxicological Profile and Summary Health Assessment for VCM in its Integrated Risk Information System (IRIS) database lowers EPA's previous risk factor estimate by a factor of 20 and concludes that "because of the consistent evidence for liver cancer in all the studies...and the weaker association for other sites, it is concluded that the liver is the most sensitive site, and protection against liver cancer will protect against possible cancer induction in other tissues."<sup>[26]</sup>

A 1998 front-page series in the Houston Chronicle claimed the vinyl industry has manipulated vinyl chloride studies to avoid liability for worker exposure and to hide extensive and severe chemical spills into local communities.<sup>[27]</sup> Retesting of community residents in 2001 by the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) found dioxin levels similar to those in a comparison community in Louisiana and to the U.S. population.<sup>[28]</sup> Cancer rates in the community were similar to Louisiana and US averages.<sup>[29]</sup>

## Dioxins

The environmentalist group Greenpeace has advocated the global phase-out of PVC because they claim dioxin is produced as a byproduct of vinyl chloride manufacture and from incineration of waste PVC in domestic garbage. The European Industry, however, asserts that it has improved production processes to minimize dioxin emissions.

Also, scientific tests wherein municipal refuse containing several known concentrations of PVC was burned in a commercial-scale incinerator showed no relationship between the PVC content of the waste and dioxin emissions.<sup>[30][31]</sup>

PVC produces HCl upon combustion almost quantitatively related to its chlorine content. Extensive studies in Europe indicate that the chlorine found in emitted dioxins is not derived from HCl in the flue gases. Instead, most dioxins arise in the condensed solid phase by the reaction of inorganic chlorides with graphitic structures in char-containing ash particles. Copper acts as a catalyst for these reactions.<sup>[32]</sup>

Dioxins are a global health threat because they persist in the environment and can travel long distances. At very low levels, near those to which the general population is exposed, dioxins have been linked to immune system suppression, reproductive disorders, a variety of cancers, and endometriosis. According to a 1994 report by the British firm, ICI Chemicals & Polymers Ltd., "It has been known since the publication of a paper in 1989 that these oxychlorination reactions [used to make vinyl chloride and some chlorinated solvents] generate polychlorinated dibenzodioxins (PCDDs) and dibenzofurans (PCDFs). The reactions include all of the ingredients and conditions necessary to form PCDD/PCDFs.... It is difficult to see how any of these conditions could be modified so as to prevent PCDD/PCDF formation without seriously impairing the reaction for which the process is designed." In other words, dioxins are an undesirable byproduct of producing vinyl chloride and eliminating the production of dioxins while maintaining the oxychlorination reaction may be difficult. Dioxins created by vinyl chloride production are released by on-site incinerators, flares, boilers, wastewater treatment systems and even in trace quantities in vinyl resins.<sup>[33]</sup> The US EPA estimate of dioxin releases from the PVC industry was 13 grams TEQ in 1995, or less than 0.5% of the total dioxin emissions in the US; by 2002, PVC industry dioxin emissions had been further reduced by 23%.<sup>[34]</sup>

The largest well-quantified source of dioxin in the US EPA inventory of dioxin sources is barrel burning of household waste.<sup>[35]</sup> Studies of household waste burning indicate consistent increases in dioxin generation with increasing PVC concentrations.<sup>[36]</sup> According to the EPA dioxin inventory, landfill fires are likely to represent an even larger source of dioxin to the environment. A survey of international studies consistently identifies high dioxin concentrations in areas affected by open waste burning and a study that looked at the homologue pattern found the sample with the highest dioxin concentration was "typical for the pyrolysis of PVC". Other EU studies indicate that PVC likely "accounts for the overwhelming majority of chlorine that is available for dioxin formation during landfill fires."<sup>[37]</sup>

The next largest sources of dioxin in the EPA inventory are medical and municipal waste incinerators.<sup>[38]</sup> Studies have shown a clear correlation between dioxin formation and chloride content and indicate that PVC is a significant contributor to the formation of both dioxin and PCB in incinerators.<sup>[39]</sup>

In February 2007, the Technical and Scientific Advisory Committee of the US Green Building



Council (USGBC) released its report on a PVC avoidance related materials credit for the LEED Green Building Rating system. The report concludes that "no single material shows up as the best across all the human health and environmental impact categories, nor as the worst" but that the "risk of dioxin emissions puts PVC consistently among the worst materials for human health impacts." <sup>[40]</sup>

## Bans

The State of California is currently considering a bill that would ban the use of PVC in consumer packaging due to the threats it poses to human and environmental health and its effect on the recycling stream.<sup>[41]</sup> Specifically, the language of the bill analysis<sup>[42]</sup> stipulates that EPA has listed PVC as a carcinogen. It also further cites that there are concerns about the leaching of phthalates and lead from the PVC packaging.

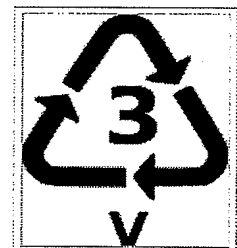
## Recycling

Post-consumer PVC is not typically recycled due to the prohibitive cost of regrinding and recompounding the resin compared to the cost of virgin (unrecycled) resin.

Some PVC manufacturers have placed vinyl recycling programs into action, recycling both manufacturing waste back into their products, as well as post consumer PVC construction materials to reduce the load on landfills.

The thermal depolymerization process can safely and efficiently convert PVC into fuel and minerals, according to the company that developed it. It is not yet in widespread use.

A new process of PVC recycling is being developed in Europe called Texiloop.<sup>[43]</sup> This process is based on a technology already applied industrially in Europe and Japan, called Vinyloop, which consists of recovering PVC plastic from composite materials through dissolution and precipitation. It strives to be a closed loop system, recycling its key solvent and hopefully making PVC a future technical nutrient.



PVC SPI code, for recycling. See Society of the Plastics Industry. The Unicode character for this symbol is U+2675 (HTML character reference &#9845;).

## See also

- Chlorinated polyvinyl chloride
- Polyvinylidene chloride
- Polyvinyl fluoride
- Polyvinylidene fluoride
- PVC recycling
- Plastic recycling

## References

## Notes

1. ^ <sup>a b c</sup> Wilkes et al. 2005, p. 414.
2. ^ A.K. van der Vegt & L.E. Govaert, Polymeren, van keten tot kunstof, ISBN 90-407-2388-5. Deformation temperature at 10 kN needle load.
3. ^ Polyvinyl Chloride (PVC) 07/08-7 Report, ChemSystems, November 2008. ([http://www.chemsystems.com/reports/search/docs/abstracts/0708\\_7\\_abs.pdf](http://www.chemsystems.com/reports/search/docs/abstracts/0708_7_abs.pdf))
4. ^ Galloway, F.M. et al. (1992) "Surface parameters from small-scale experiments used for measuring HCl transport and decay in fire atmospheres", *Fire Mater.*, 15:181-189
5. ^ Shah Rahman (June 19-20 2007). "*PVC Pipe & Fittings: Underground Solutions for Water and Sewer Systems in North America* (<http://www.institutodopvc.org/congresso2/ShahRahman.pdf>)" (PDF). *2nd BRAZILIAN PVC CONGRESS, Sao Paulo, Brazil*. <http://www.institutodopvc.org/congresso2/ShahRahman.pdf>.
6. ^ <http://www.vinylbydesign.com/site/page.asp?CID=14&DID=15>
7. ^ [http://web.archive.org/web/20070926150233/http://www.bsc.ca.gov/documents/PR07-02\\_final\\_pics.pdf](http://web.archive.org/web/20070926150233/http://www.bsc.ca.gov/documents/PR07-02_final_pics.pdf)
8. ^ Shah Rahman (October 2004). "*Thermoplastics at Work: A Comprehensive Review of Municipal PVC Piping Products* (<http://www.oildompublishing.com/uceditorialarchive/october04/oct04utech.pdf>)" (PDF). *Underground Construction*: 56–61. <http://www.oildompublishing.com/uceditorialarchive/october04/oct04utech.pdf>.
9. ^ uPVC Windows, Doors ([http://www.windowstoday.co.uk/products\\_pvcu.htm](http://www.windowstoday.co.uk/products_pvcu.htm))
10. ^ PolyVinyl (Poly Vinyl Chloride) in Construction (<http://www.azom.com/details.asp?ArticleID=988>)
11. ^ Fascia, Guttering, Fascias, PVCu Soffits, Roofing, Cladding (<http://www.windowstoday.co.uk/cladding.htm>)
12. ^ PVC Products - Greenpeace international (<http://www.greenpeace.org/international/campaigns/toxics/polyvinyl-chloride/pvc-products>)
13. ^ Environmentally conscious buildings (<http://www.berwick-upon-tweed.gov.uk/buildingcontrol/conscious.htm>)
14. ^ "How safe is your sex toy? (<http://www.greenpeace.org.uk/blog/toxics/bad-vibrations-we-expose-an-eu-sex-scandal>)". <http://www.greenpeace.org.uk/blog/toxics/bad-vibrations-we-expose-an-eu-sex-scandal>. Retrieved 2008-05-15.
15. ^ See directive 2005/84/EC ([http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2005/l\\_344/l\\_34420051227en00400043.pdf](http://europa.eu.int/eur-lex/lex/LexUriServ/site/en/oj/2005/l_344/l_34420051227en00400043.pdf))
16. ^ Phthalates and children's toys ([http://www.phthalates.org/yourhealth/childrens\\_toys.asp](http://www.phthalates.org/yourhealth/childrens_toys.asp)), [www.phthalates.org](http://www.phthalates.org), undated (accessed 2 February 2007)
17. ^ EU Risk assessment summary report (<http://www.dinp-facts.com/upload/documents/document2.pdf>)
18. ^ Vinyl shower curtains a 'volatile' hazard, study says (<http://www.canada.com/cityguides/winnipeg/info/story.html?id=dfc49cb3-b104-4d4a-a449-14e4faf17e2b>)
19. ^ Bornehag et al. (2004). "*The Association Between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case-Control Study* (<http://www.medscape.com/viewarticle/491620>)". *Environmental Health Perspectives* **112** (14): 1393–1397. <http://www.medscape.com/viewarticle/491620>.
20. ^ Phthalate Information Center Blog: More good news from Europe ([http://blog.phthalates.org/archives/2007/01/more\\_good\\_news.html](http://blog.phthalates.org/archives/2007/01/more_good_news.html))
21. ^ Business Wire (21 November 2005). "CHW Switches to PVC/DEHP-Free Products to Improve Patient Safety and Protect the Environment ([http://www.findarticles.com/p/articles/mi\\_m0EIN/is\\_2005\\_Nov\\_21/ai\\_n15863110](http://www.findarticles.com/p/articles/mi_m0EIN/is_2005_Nov_21/ai_n15863110))". *Business Wire*. [http://www.findarticles.com/p/articles/mi\\_m0EIN/is\\_2005\\_Nov\\_21/ai\\_n15863110](http://www.findarticles.com/p/articles/mi_m0EIN/is_2005_Nov_21/ai_n15863110).
22. ^ "Safety Assessment of Di(2-ethylhexyl)phthalate (DEHP) Released from PVC Medical Devices (<http://www.fda.gov/cdrh/ost/dehp-pvc.pdf>)" (PDF). <http://www.fda.gov/cdrh/ost/dehp-pvc.pdf>.
23. ^ Creech and Johnson (March 1974). "*Angiosarcoma of liver in the manufacture of polyvinyl chloride*. ([http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list\\_uids=4856325&dopt=Citation](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=4856325&dopt=Citation))". *Journal of occupational medicine. : official publication of the Industrial Medical Association*. **16** (3): 150–1. [http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list\\_uids=4856325&dopt=Citation](http://www.ncbi.nlm.nih.gov/entrez/query.fcgi?cmd=Retrieve&db=PubMed&list_uids=4856325&dopt=Citation).

24. ^ Epidemiologic Notes and Reports Angiosarcoma of the Liver Among Polyvinyl Chloride Workers – Kentucky, Centers for Disease Control and Prevention Web site. 1997. Available at: <http://www.cdc.gov/mmwr/preview/mmwrhtml/00046136.htm>
25. ^ National Emission Standards for Hazardous Air Pollutants (NESHAP) for Vinyl Chloride Subpart F, OMB Control Number 2060-0071, EPA ICR Number 0186.09 (Federal Register: (<http://www.epa.gov/fedrgstr/EPA-AIR/2001/September/Day-25/a23920.htm>) September 25 2001 (Volume 66, Number 186))
26. ^ EPA Toxicologica Review of Vinyl Chloride i Support of Informaiton on the IRIS. May 2000
27. ^ Jim Morris, "In Strictest Confidence . The chemical industry's secrets," Houston Chronicle. Part One: "Toxic Secrecy," June 28, 1998, pgs. 1A, 24A-27A; Part Two: "High-Level Crime," June 29, 1998, pgs. 1,A, 8A, 9A; and Part Three: "Bane on the Bayou," July 26, 1998, pgs. 1A, 16A.]
28. ^ "ATSDR Study Finds Dioxin Levels in Calcasieu Parish Residents Similar to National Levels," available at: <http://www.atsdr.cdc.gov/NEWS/calcasieula031506.html>; "ATSDR Study Finds Dioxin Levels Among Lafayette Parish Residents Similar to National Levels," available at: <http://www.atsdr.cdc.gov/NEWS/lafayettela031606.html>; ATSDR Report: Serum Dioxin Levels In Residents Of Calcasieu Parish, Louisiana, October 2005, Publication Number PB2006-100561, available from the National Technical Information Services, Springfield, Virginia, phone: 1-800-553-6847/1-703-605-6244
29. ^ "Calcasieu Cancer Rates Similar to State/National Averages." News Release, State of Louisiana Dept. of Health and Hospitals. January 17, 2002
30. ^ National Renewable Energy Laboratory, "Polyvinyl Chloride Plastics in Municipal Solid Waste Combustion," NREL/TP-430- 5518, Golden CO, April 1993
31. ^ Rigo, H.G., Chandler, A. J., and Lanier, W.S., "The Relationship between Chlorine in Waste Streams and Dioxin Emissions from Waste Combustor Stacks," American Society of Mechanical Engineers Report CRTD, Vol 36, New York 1995
32. ^ Steiglitz, L., and Vogg, H., "Formation Decomposition of Polychlorodibenzodioxins and Furans in Municipal Waste," Report KFK4379, Laboratorium fur Isotopentechnik, Institut for Heize Chemi, Kerforschungszentrum Karlsruhe, Feb 1988.
33. ^ Pat Costner etal, "PVC: A Primary Contributor to the U.S. Dioxin Burden (<http://www.mindfully.org/Plastic/PVC-Primary-Contributor-Dioxin.htm>) ; Comments submitted to the U.S. EPA Dioxin Reassessment," (Washington, D.C. Greenpeace U.S.A., February 1995
34. ^ US EPA, The Inventory of Sources and Environmental Releases of Dioxin-Like Compounds in the United States: The Year 2002 Update, May 2007
35. ^ US EPA2005
36. ^ Costner, Pat, (2005), "Estimating Releases and Prioritizing Sources in the Context of the Stockholm Convention" ([http://www.pops.int/documents/meetings/cop\\_2/followup/toolkit/submissions/IPEN%20Comments/Estimating%20Dioxin%20Releases%20English.pdf](http://www.pops.int/documents/meetings/cop_2/followup/toolkit/submissions/IPEN%20Comments/Estimating%20Dioxin%20Releases%20English.pdf)) , International POPs Elimination Network, Mexico.
37. ^ Costner 2005
38. ^ Beychok, M.R., *A data base of dioxin and furan emissions from municipal refuse incinerators*, Atmospheric Environment, Elsevier B.V., January 1987
39. ^ Katami, Takeo, et al. (2002) "Formation of PCDDs, PCDFs, and Coplanar PCBs from Polyvinyl Chloride during Combustion in an Incinerator" Environ. Sci. Technol., 36, 1320–1324. and Wagner, J., Green, A. 1993. Correlation of chlorinated organic compound emissions from incineration with chlorinated organic input. Chemosphere 26 (11): 2039–2054. and Thornton, Joe (2002) "Environmental Impacts of polyvinyl Chloride Building Materials", Healthy Building Network, Washington, DC.
40. ^ The USGBC document can be found on line at <https://www.usgbc.org/ShowFile.aspx?DocumentID=2372> An analysis by the Healthy Building NETwork is at [http://www.pharosproject.net/wiki/index.php?title=USGBC\\_TSAC\\_PVC](http://www.pharosproject.net/wiki/index.php?title=USGBC_TSAC_PVC)
41. ^ AB 2505 Californians Against Waste [http://www.cawrecycles.org/issues/current\\_legislation/ab2505\\_08](http://www.cawrecycles.org/issues/current_legislation/ab2505_08)
42. ^ [http://info.sen.ca.gov/pub/07-08/bill/asm/ab\\_2501-2550/ab\\_2505\\_cfa\\_20080415\\_092217\\_asm\\_comm.html](http://info.sen.ca.gov/pub/07-08/bill/asm/ab_2501-2550/ab_2505_cfa_20080415_092217_asm_comm.html)
43. ^ [http://www.pvcinfo.be/bestanden/Progress%20report%202002\\_fr.pdf](http://www.pvcinfo.be/bestanden/Progress%20report%202002_fr.pdf), Page 11, "Mise A Jour Du Projet, Projet Ferrari - Texilooop

## Bibliography

- Wilkes, Charles E.; Summers, James W.; Daniels, Charles Anthony; Berard, Mark T. (2005). *PVC Handbook* (<http://books.google.com/books?id=YUkJNI9QYsUC>) (illustrated ed.). Hanser Verlag. ISBN 9781569903797. <http://books.google.com/books?id=YUkJNI9QYsUC..>

## Movies

- *Blue Vinyl* (2002). Directed by Daniel B. Gold and Judith Helfand. Learn more about it at [2] (<http://www.bluevinyl.org>)
- *Sam Suds and the Case of PVC, the Poison Plastic* (2006). Watch it at [3] (<http://www.pvcfree.org>)
- *An Overview of the Benefits of Vinyl* (2006) by Dr. Patrick Moore, founding member of Greenpeace and former Director of Greenpeace International. See it at [4] (<http://www.vinylnewsservice.net>)

## External links

- PharosWiki entry on PVC (<http://www.pharosproject.net/wiki/index.php?title=PVC>) - more detailed referenced information on health issues associated with PVC life cycle.
- PVC Information (<http://www.pvcinformation.org/>) "*Vinyl is all around us, but no other plastic poses such direct environmental and human health risks.*"
- The Association between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case-Control Study (<http://ehp.niehs.nih.gov/members/2004/7187/7187.html>)
- Polyvinyl Chloride - General Info (<http://www.ejnet.org/plastics/pvc/>) "*PVC – Toxic Plastic*"
- The European PVC Portal (European Council of Vinyl Manufacturers) (<http://www.ecvm.org>)
- European Council of Plasticisers and Intermediates (<http://www.ecpi.org>)
- Uni-Bell PVC Pipe Association (<http://www.uni-bell.org>)
- An introduction to vinyl (<http://www.azom.com/details.asp?ArticleID=987>)
- The Vinyl Council of Canada (<http://www.plastics.ca/vinyl/default.php?>)

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Categories: Plastics | Vinyl polymers | Dielectrics | Nonwoven fabrics | Thermoplastics | Recyclable materials

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
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## International Occupational Safety and Health Information Centre (CIS)


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[\[Risk Notes\]](#)
[\[Risk Phrases\]](#)
[\[Safety Phrases\]](#)
[\[Danger Symbols\]](#)
**POLYSTYRENE**
**ICSC: 1043**  
**November 2003**

 Benzene, ethenyl-, homopolymer  
 Ethenylbenzene, homopolymer
**CAS No: 9003-53-6** $(C_8H_8)_x$ **RTECS No: WL6475000****Molecular mass: 10 000-300 000**

TYPES OF HAZARD / EXPOSURE	ACUTE HAZARDS / SYMPTOMS	PREVENTION	FIRE FIGHTING
<b>FIRE</b>	Combustible. Gives off irritating or toxic fumes (or gases) in a fire.	NO open flames.	Powder, water spray, foam, carbon dioxide.
<b>EXPLOSION</b>			
<b>EXPOSURE</b>		<b>PREVENT DISPERSION OF DUST!</b>	
<b>Inhalation</b>		Avoid inhalation of dust.	
<b>Skin</b>			
<b>Eyes</b>		Safety goggles, or eye protection in combination with breathing protection if powder.	
<b>Ingestion</b>			

SPILLAGE DISPOSAL	PACKAGING & LABELLING
Ventilation. Remove all ignition sources. Sweep spilled substance into labelled and suitable containers. (Extra personal protection: P1 filter respirator for inert particles.)	





EMERGENCY RESPONSE	STORAGE

**IMPORTANT DATA**

<b>Physical State; Appearance</b> COLOURLESS SOLID IN VARIOUS FORMS  <b>Chemical dangers</b> The substance decomposes on heating above 300°C producing toxic fumes including styrene. The substance decomposes on burning producing irritating fumes. Reacts with strong oxidants.  <b>Occupational exposure limits</b> TLV not established. MAK not established.	<b>Inhalation risk</b> A nuisance-causing concentration of airborne particles can be reached quickly when dispersed, especially if powdered.  <b>Effects of short-term exposure</b> May cause mechanical irritation.
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PHYSICAL PROPERTIES	ENVIRONMENTAL DATA
Melting point: 240°C ✓ Relative density (water = 1): 1.04-1.13 Flash point: 345-360°C Auto-ignition temperature: 427°C	

NOTES

<b>IPCS</b> International Programme on Chemical Safety	   	Prepared in the context of cooperation between the International Programme on Chemical Safety and the European Commission © IPCS 2003
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# Polystyrene

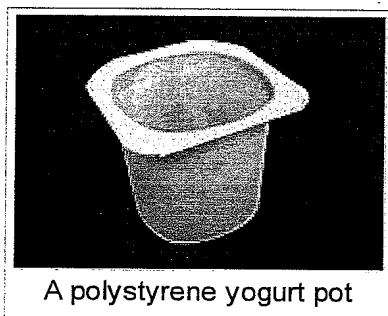
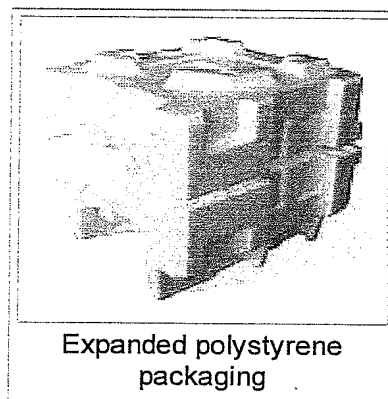
From Wikipedia, the free encyclopedia

**Polystyrene** (pronounced /ˌpɒliˈstaɪriːn/) (IUPAC **Poly(1-phenylethane-1,2-diyl)**), sometimes abbreviated **PS**, is an aromatic polymer made from the aromatic monomer styrene, a liquid hydrocarbon that is commercially manufactured from petroleum by the chemical industry. Polystyrene is one of the most widely used kinds of plastic.

Polystyrene is a thermoplastic substance, which is in solid (glassy) state at room temperature, but flows if heated above its glass transition temperature (for molding or extrusion), and becoming solid again when cooling off. Pure solid polystyrene is a colorless, hard plastic with limited flexibility. It can be cast into molds with fine detail. Polystyrene can be transparent or can be made to take on various colors.

Solid polystyrene is used, for example, in disposable cutlery, plastic models, CD and DVD cases, and smoke detector housings. Products made from foamed polystyrene are nearly ubiquitous, for example packing materials, insulation, and foam drink cups.

Polystyrene can be recycled, and has the number "6" as its recycling symbol. Unrecycled polystyrene, which does not biodegrade, is often abundant in the outdoor environment, particularly along shores and waterways, and is a form of pollution.



## Contents

- 1 History
- 2 Structure and properties
- 3 Forms produced
  - 3.1 Extruded polystyrene
  - 3.2 Foams
    - 3.2.1 Expanded polystyrene foam
    - 3.2.2 Extruded polystyrene foam
  - 3.3 Copolymers
- 4 Disposal and environmental issues
  - 4.1 Environmental impact
  - 4.2 Recycling
  - 4.3 Incineration
  - 4.4 Burial
  - 4.5 Reducing

- 5 Finishing
- 6 Health and fire hazards
- 7 See also
- 8 References
- 9 External links

## History

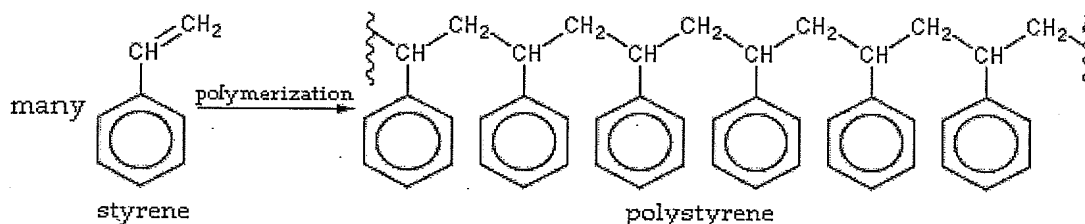
Polystyrene was discovered in 1839 by Eduard Simon,<sup>[1]</sup> an apothecary in Berlin. From storax, the resin of the Turkish sweetgum tree (*Liquidambar orientalis*), he distilled an oily substance, a monomer which he named styrol. Several days later, Simon found that the styrol had thickened, presumably from oxidation, into a jelly he dubbed styrol oxide ("Styroloxyd"). By 1845 English chemist John Blyth and German chemist August Wilhelm von Hofmann showed that the same transformation of styrol took place in the absence of oxygen. They called their substance metastyrol. Analysis later showed that it was chemically identical to Styroloxyd. In 1866 Marcelin Berthelot correctly identified the formation of metastyrol from styrol as a polymerization process. About 80 years went by before it was realized that heating of styrol starts a chain reaction which produces macromolecules, following the thesis of German organic chemist Hermann Staudinger (1881–1965). This eventually led to the substance receiving its present name, polystyrene.

The company I. G. Farben began manufacturing polystyrene in Ludwigshafen, Germany, about 1931, hoping it would be a suitable replacement for die-cast zinc in many applications. Success was achieved when they developed a reactor vessel that extruded polystyrene through a heated tube and cutter, producing polystyrene in pellet form.

In 1959, the Koppers Company in Pittsburgh, Pennsylvania, developed expanded polystyrene (EPS) foam.

## Structure and properties

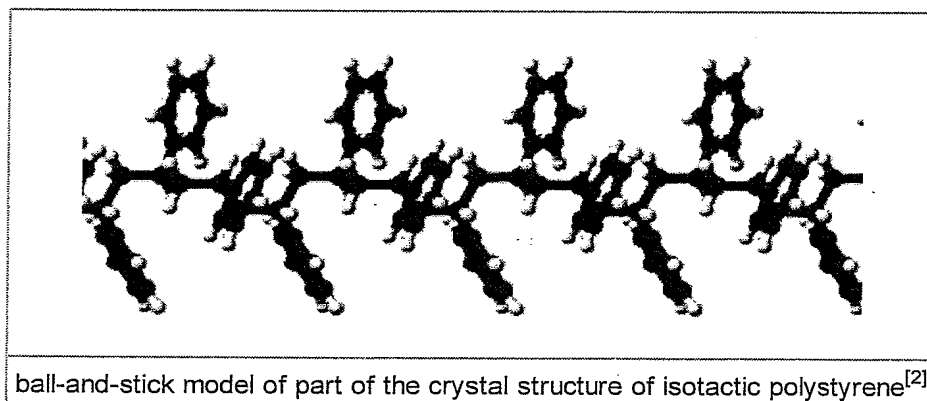
The chemical makeup of polystyrene is a long chain hydrocarbon with every other carbon connected to a phenyl group (the name given to the aromatic ring benzene, when bonded to complex carbon substituents). Polystyrene's chemical formula is  $(C_8H_8)_n$ ; it contains the chemical elements carbon and hydrogen. Because it is an aromatic hydrocarbon, it burns with an orange-yellow flame, giving off soot, as opposed to non-aromatic hydrocarbon polymers such as polyethylene, which burn with a light yellow flame (often with a blue tinge) and no soot. Complete oxidation of polystyrene produces only carbon dioxide and water vapor.



A 3-D model would show that each of the chiral backbone carbons lies at the center of a



tetrahedron, with its 4 bonds pointing toward the vertices. Say the -C-C- bonds are rotated so that the backbone chain lies entirely in the plane of the diagram. From this flat schematic, it is not evident which of the phenyl (benzene) groups are angled toward us from the plane of the diagram, and which ones are angled away. The isomer where all of them are on the same side is called *isotactic* polystyrene, which is not produced commercially.



Ordinary *atactic* polystyrene has these large phenyl groups randomly distributed on both sides of the chain. This random positioning prevents the chains from ever aligning with sufficient regularity to achieve any crystallinity, so the plastic has no melting temperature,  $T_m$ . But metallocene-catalyzed polymerization can produce an ordered *syndiotactic* polystyrene with the phenyl groups on alternating sides. This form is highly crystalline with a  $T_m$  of 270 °C.

Extruded polystyrene is about as strong as unalloyed aluminium, but much more flexible and much lighter (1.05 g/cc vs. 2.70 g/cc for aluminium).

## Forms produced

Polystyrene is commonly produced in three forms: extruded polystyrene, expanded polystyrene foam, and extruded polystyrene foam, each with a variety of applications. Polystyrene copolymers are also produced; these contain one or more other monomers in addition to styrene. In recent years the expanded polystyrene composites with cellulose<sup>[5][6]</sup> and starch<sup>[7]</sup> have also been produced.

Extruded polystyrene foam insulation is sold under the trademark Styrofoam by Dow Chemical. This term is often used informally for other foamed

Properties	
Density	1050 kg/m <sup>3</sup>
Density of EPS	25-200 kg/m <sup>3</sup>
Dielectric constant	2.4–2.7
Specific gravity	1.05
Electrical conductivity (s)	10 <sup>-16</sup> S/m
Thermal conductivity (k)	0.08 W/(m·K)
Young's modulus ( <i>E</i> )	3000-3600 MPa
Tensile strength ( <i>σ</i> <sub>t</sub> )	46–60 MPa
Elongation at break	3–4%
Notch test	2–5 kJ/m <sup>2</sup>
Glass temperature	95 °C
Melting point <sup>[3]</sup>	<u>240 °C</u> ✓

polystyrene products.

Polystyrene is used in some polymer-bonded explosives:

Vicat B	90 °C <sup>[4]</sup>
Linear expansion coefficient (a)	$8 \cdot 10^{-5}$ /K
Specific heat (c)	1.3 kJ/(kg·K)
Water absorption (ASTM)	0.03–0.1
Decomposition	X years, still decaying

### Polystyrene PBX examples

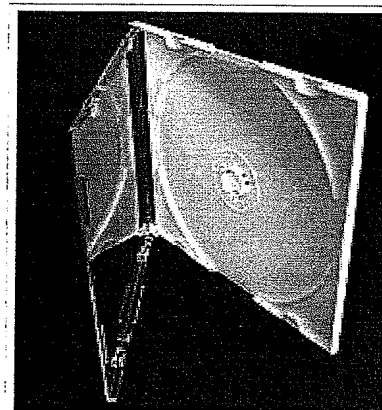
Name	Explosive ingredients	Binder ingredients
PBX-9205	RDX 92%	Polystyrene 6%; DOP 2%
PBX-9007	RDX 90%	Polystyrene 9.1%; DOP 0.5%; resin 0.4%

It is also a component of napalm<sup>[8]</sup> and a component of most designs of hydrogen bombs.

### Extruded polystyrene

Extruded polystyrene (PS) is economical, and is used for producing plastic model assembly kits, plastic cutlery, CD "jewel" cases, smoke detector housings, license plate frames, and many other objects where a fairly rigid, economical plastic is desired. Production methods include stamping and injection molding.

Polystyrene Petri dishes and other laboratory containers such as test tubes and microplates play an important role in biomedical research and science. For these uses, articles are almost always made by injection molding, and often sterilized post-molding, either by irradiation or treatment with ethylene oxide. Post-mold surface modification, usually with oxygen-rich plasmas, is often done to introduce polar groups. Much of modern biomedical research relies on the use of such products; they therefore play a critical role in pharmaceutical research.<sup>[9]</sup>

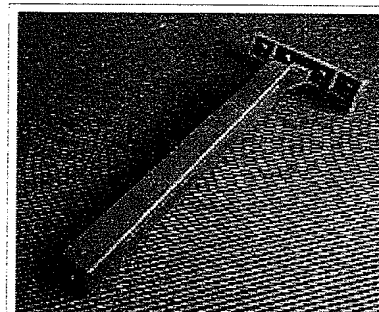


CD case made from General Purpose Polystyrene (GPPS) and High Impact Polystyrene (HIPS)

### Foams

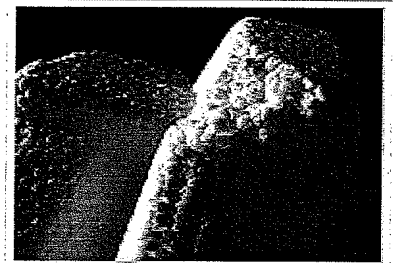
Polystyrene foams are good thermal insulators, and are therefore often used as building insulation materials, such as in structural insulated panel building systems. They are also used for non-weight-bearing architectural structures (such as ornamental pillars).

### Expanded polystyrene foam



Disposable polystyrene razor

Expanded polystyrene foam (EPS) is usually white and made of expanded polystyrene beads. Familiar uses include packing "peanuts" and molded packing material for cushioning fragile items inside boxes. It is commonly packaged as rigid panels (size 4 by 8 or 2 by 8 square feet in the United States), which are also known as "bead-board". Thermal resistivity is usually about 28 m·K/W (or R-4 per inch in American customary units). Some EPS boards have a flame spread of less than 25 and a smoke-developed index of less than 450, which means they can be used without a fire barrier (but require a 15 minute thermal barrier) according to US building codes. A growing use of EPS in construction are Insulating concrete forms.



Close up of expanded polystyrene packaging

### Extruded polystyrene foam

Extruded polystyrene foam (XPS) has air inclusions which gives it moderate flexibility, a low density, and a low thermal conductivity.

Extruded polystyrene material is also used in crafts and model building, particularly architectural models. Foamed between two sheets of paper, it makes a more uniform substitute for corrugated cardboard. Thermal resistivity is usually about 35 m·Kelvin/W (or R-5 per inch in American customary units).

Trade names for XPS include "Styrofoam" and "Foamcore". ("Styrofoam" is often also used as a generic name for all polystyrene foams.)

### Copolymers

Pure polystyrene is brittle, but hard enough that a fairly high-performance product can be made by giving it some of the properties of a stretchier material, such as polybutadiene rubber. The two such materials can never normally be mixed because of the amplified effect of intermolecular forces on polymer insolubility (see plastic recycling), but if polybutadiene is added during polymerization it can become chemically bonded to the polystyrene, forming a graft copolymer which helps to incorporate normal polybutadiene into the final mix, resulting in **high-impact polystyrene** or **HIPS**, often called "high-impact plastic" in advertisements. One commercial name for HIPS is Bextrene. Common applications of HIPS include toys and product casings. HIPS is usually injection molded in production. Autoclaving polystyrene can compress and harden the material.

Several other copolymers are also used with styrene. Acrylonitrile butadiene styrene or ABS plastic is similar to HIPS: a copolymer of acrylonitrile and styrene, toughened with polybutadiene. Most electronics cases are made of this form of polystyrene, as are many sewer pipes. ABS pipes may become brittle over time. SAN is a copolymer of styrene with acrylonitrile, and SMA one with maleic anhydride. Styrene can be copolymerized with other monomers; for example, divinylbenzene for cross-linking the polystyrene chains.

### Disposal and environmental issues

Polystyrene is not easily recycled because of its light weight (especially if foamed) and its low scrap value. It is generally not accepted in kerbside (curbside) collection recycling programs. In Germany, however, polystyrene is collected, as a consequence of the

packaging law (Verpackungsverordnung) that requires manufacturers to take responsibility for recycling or disposing of any packaging material they sell.

On the other hand, great advances have been made in recycling expanded polystyrene at an industrial level. Many different methods of densification have been developed. This increase in density, usually greater than 15#/cubic foot makes clean polystyrene a good profit center in recycling operations. Some industrial polystyrene manufacturers accept post consumer EPS for recycling. As an example Dart Container Corporation in Mason, Michigan has an ongoing post consumer recycling operation as well as an industrial EPS scrap recycling operation.

## Environmental impact

Discarded polystyrene does not biodegrade and is resistant to photolysis.<sup>[10]</sup> Since the foamed kinds not only float on water, but also blow in the wind, it is often abundant in the outdoor environment, particularly along shores and waterways. According to the California Coastal Commission, it is now a principal component of marine debris. The plastic may also be harmful to wild animals if it is ingested by them.

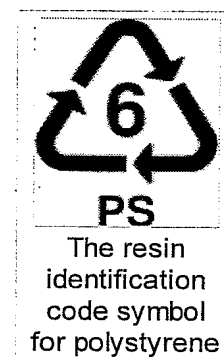
Polystyrene foams are produced using blowing agents that form bubbles and expand the foam. In expanded polystyrene, these are usually hydrocarbons such as pentane, which may pose a flammability hazard in manufacturing or storage of newly manufactured material, but have relatively mild environmental impact. However, extruded polystyrene is usually made with HCFC blowing agents which have effects on ozone depletion and on global warming. Their ozone depletion potential is greatly reduced relative to CFCs which were formerly used, but their global warming potential can be on the order of 1000 or more, meaning it has 1000 times greater effect on global warming than does carbon dioxide.<sup>[11]</sup>

While there is less concern about the health effects of EPS itself, the brominated flame retardants used in most EPS foam (decaBDE or hexabromocyclododecane are the most commonly used) create health and environmental risks that are generating even more significant concern.<sup>[12][13]</sup>

In 2009, a company designed a potential environmentally friendly replacement for polystyrene packaging created from fungi and agricultural waste, which it calls Acorn.<sup>[14]</sup>

## Recycling

Currently, the majority of polystyrene products are not recycled because of a lack of consumer awareness regarding suitable recycling facilities and collection methods. Expanded polystyrene scrap can be easily added to products such as EPS insulation sheets and other EPS materials for construction applications. Commonly, manufacturers cannot obtain sufficient scrap because of the aforementioned collection issues. When it is not used to make more EPS, foam scrap can be turned into clothes hangers, park benches, flower pots, toys, rulers, stapler bodies, seedling containers, picture frames, and architectural molding from recycled PS.<sup>[15]</sup>



Recycled EPS is also used in many metal casting operations. It can be combined with cement to be used as an insulating amendment in the making of concrete foundations. American manufacturers have produced insulated concrete forms made with

approximately 80% recycled EPS since 1993. However, polystyrene recycling is not a closed loop, producing more polystyrene; polystyrene cups and other packaging materials are instead usually used as fillers in other plastics, or in other items that cannot themselves be recycled and are thrown away.

## Incineration

If polystyrene is properly incinerated at high temperatures, the only chemicals generated are water, carbon dioxide, some volatile compounds, and carbon soot.<sup>[16]</sup> According to the American Chemistry Council, when polystyrene is incinerated in modern facilities, the final volume is 1% of the starting volume; most of the polystyrene is converted into carbon dioxide, water vapor, and heat. Because of the amount of heat released, it is sometimes used as a power source for steam or electricity generation.<sup>[17]</sup>

According to the *Journal of Chromatography*, When polystyrene was burned at temperatures of 800-900 Celsius (the typical range of a modern incinerator), the products of combustion consisted of "a complex mixture of polycyclic aromatic hydrocarbons (PAHs) from alkyl benzenes to benzo[ghi]perylene. Over 90 different compounds were identified in combustion effluents from polystyrene."<sup>[18]</sup>

When burned without enough oxygen or at lower temperatures (as in a campfire or a household fireplace), polystyrene can produce polycyclic aromatic hydrocarbons, carbon black, and carbon monoxide, as well as styrene monomers.<sup>[16][19]</sup>

## Burial

Foam cups and other polystyrene products can be safely buried in landfills, since it is as stable as concrete or brick. No plastic film is required to protect the air and underground water.

## Reducing

Restricting the use of foamed polystyrene takeout food packaging is a priority of many solid waste environmental organizations. A campaign to achieve the first ban of polystyrene foam from the food & beverage industry in Canada has been launched in Toronto as of January 2007, by local non-profit organization NaturoPack.<sup>[20]</sup>

## Finishing

In the United States, environmental protection regulations prohibit the use of solvents on polystyrene (which would dissolve the polystyrene and de-foam most foams anyway).

Some acceptable finishing materials are

- Water-based paint (artists have created paintings on polystyrene with gouache)
- Mortar or acrylic/cement render, often used in the building industry as a weather-hard overcoat that hides the foam completely after finishing the objects.
- Cotton wool or other fabrics used in conjunction with a stapling implement.

## Health and fire hazards

There is concern about the trace presence of polystyrene's production chemicals in the final plastic product, most of which are toxic if not removed. For instance benzene, which is used to produce ethylbenzene for styrene, is a known carcinogen. As well, unpolymerized styrene may pose health risks. Nevertheless, the EPA states:

“ Styrene is primarily used in the production of polystyrene plastics and resins. Acute (short-term) exposure to styrene in humans results in mucous membrane and eye irritation, and gastrointestinal effects. Chronic (long-term) exposure to styrene in humans results in effects on the central nervous system (CNS), such as headache, fatigue, weakness, and depression, CNS dysfunction, hearing loss, and peripheral neuropathy. Human studies are inconclusive on the reproductive and developmental effects of styrene; several studies did not report an increase in developmental effects in women who worked in the plastics industry, while an increased frequency of spontaneous abortions and decreased frequency of births were reported in another study. Several epidemiologic studies suggest there may be an association between styrene exposure and an increased risk of leukemia and lymphoma. However, the evidence is inconclusive due to confounding factors. EPA has not given a formal carcinogen classification to styrene. <sup>[21]</sup> ”

Polystyrene is classified according to DIN4102 as a "B3" product, meaning highly flammable or "easily ignited." Consequently, although it is an efficient insulator at low temperatures, its use is prohibited in any exposed installations in building construction if the material is not flame retardant, e.g., with hexabromocyclododecane. It must be concealed behind drywall, sheet metal or concrete. Foamed polystyrene plastic materials have been accidentally ignited and caused huge fires and losses, for example at the Düsseldorf International Airport, the Channel tunnel (where polystyrene was inside a railcar that caught on fire), and the Browns Ferry Nuclear Power Plant (where fire breached a fire retardant and reached the foamed plastic underneath, inside a firestop that had not been tested and certified in accordance with the final installation).

In addition to fire hazard, polystyrene can be dissolved by substances that contain acetone (such as most aerosol paint sprays), and by cyanoacrylate glues.

## See also

- Bioplastic
- Insulating concrete forms
- Greatpac Sdn. Bhd.
- Geofoam
- Structural insulated panel
- Styrofoam
- ThermaSAVE

## References

- <sup>1</sup>. <sup>^</sup> The history of plastics  
(<http://inventors.about.com/od/pstartinventions/a/plastics.htm>)
- <sup>2</sup>. <sup>^</sup> G. Natta, P. Corradini, I.W. Bassi (1960).

- "Crystal structure of isotactic polystyrene". // *Nuovo Cimento* **15**: 68–82.  
doi:10.1007/BF02731861 (<http://dx.doi.org/10.1007%2FBF02731861>) .
3. ^ International Labour Organisation chemical safety card for polystyrene ([http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/\\_icsc10/icsc1043.htm](http://www.ilo.org/public/english/protection/safework/cis/products/icsc/dtasht/_icsc10/icsc1043.htm))
  4. ^ A.K. van der Vegt & L.E. Govaert, *Polymeren, van keten tot kunstof*, ISBN 90-407-2388-5
  5. ^ Doroudiani S, Kortschot MT (2004) "Expanded Wood Fiber Polystyrene Composites: Processing-Structure-Mechanical Properties Relationships" *Journal of Thermoplastic Composite Materials* **17**:13-30.
  6. ^ Doroudiani S, Chaffey CE, Kortschot MT (2002) "Sorption and Diffusion of Carbon Dioxide in Wood-Fiber/Polystyrene Composites" *Journal of Polymer Science Part B: Polymer Physics Edition* **40**:723-35.
  7. ^ Mihai M, Huneault MA, Favis BD (2007) "Foaming of Polystyrene/ Thermoplastic Starch Blends", *Journal of Cellular Plastics* **43**:215-236.
  8. ^ Napalm (<http://www.globalsecurity.org/military/systems/munitions/napalm.htm>)
  9. ^ Jed Norton. "Blue Foam, Pink Foam and Foam Board (<http://www.barrule.com/workshop/images/info/foams/index.htm>) ". Antenociti's Workshop.  
<http://www.barrule.com/workshop/images/info/foams/index.htm>. Retrieved 2008-01-29.
  10. ^ Bandyopadhyay, Abhijit; Chandra Basak, G. (2007), "Studies on photocatalytic degradation of polystyrene", *Materials Science and Technology* **23** (3): 307–317, doi:10.1179/174328407X158640 (<http://dx.doi.org/10.1179%2F174328407X158640>)
  11. ^ IPCC Third Assessment Report, Climate Change 2001: Working Group I: The Scientific Basis. Section 6.12.2 Direct GWPs. [http://www.grida.no/publications/other/ipcc\\_tar/?src=/climate/ipcc\\_tar/wg1/248.htm](http://www.grida.no/publications/other/ipcc_tar/?src=/climate/ipcc_tar/wg1/248.htm)
  12. ^ EPA information on HBCD. <http://www.epa.gov/hpvis/rbp/HBCD.3194556.Web.RBP.31308.pdf>
  13. ^ More EPA information and other presentations. <http://www.durisolbuild.com/insulated-concrete-forms.shtml>
  14. ^ Shin L. (2009). Using Fungi to Replace Styrofoam (<http://greeninc.blogs.nytimes.com/2009/04/13/using-fungi-to-replace-styrofoam/>) . *NY Times*.
  15. ^ Polystyrene recycling. (<http://pspc.intoweb.co.za/index.php?page=recycle1>) Polystyrene packaging council. Retrieved on 2009-03-06.
  16. ^ <sup>a</sup> <sup>b</sup> Polystyrene Foam Burning Danger (<http://www.newton.dep.anl.gov/askasci/chem00/chem00053.htm>)
  17. ^ *Ease of Disposal* ([http://www.americanchemistry.com/s\\_plastics/sec\\_pfpfg.asp?CID=1434&did=5226](http://www.americanchemistry.com/s_plastics/sec_pfpfg.asp?CID=1434&did=5226)) , [http://www.americanchemistry.com/s\\_plastics/sec\\_pfpfg.asp?CID=1434&did=5226](http://www.americanchemistry.com/s_plastics/sec_pfpfg.asp?CID=1434&did=5226), retrieved 2009-06-25.
  18. ^ [1] (<http://www.ejnet.org/plastics/polystyrene/disposal.html>) R.A, Hawley-Fedder, M.L. Parsons, and F.W. Karasek, "Products Obtained During Combustion of Polymers Under Simulated Incinerator Conditions, II Polystyrene," *Journal of Chromatography*, #315, 1984, Elsevier Science Publishers B.V., Amsterdam, The Netherlands.
  19. ^ Burning Polystyrene Foam (<http://www.newton.dep.anl.gov/askasci/chem00/chem00532.htm>)
  20. ^ Naturopack Campaign Page (<http://naturopack.org/getittogogreenmain.html>)
  21. ^ Styrene | Technology Transfer Network Air Toxics Web site | US EPA (<http://www.epa.gov/ttn/atw/hlthef/styrene.html>)

## External links

- Polystyrene (<http://www.pslc.ws/mactest/styrene.htm>) - The University of Southern Mississippi
- SPI resin identification code (<http://www.plasticsindustry.org/AboutPlastics/content.cfm?ItemNumber=825&navItemNumber=1124>) - Society of the Plastics Industry

- Bacteria Turns Styrofoam into Biodegradable Plastic (<http://www.sciam.com/article.cfm?chanID=sa003&articleID=0007B0AE-88AF-13FF-88AF83414B7F0000>) - Scientific American, February 27, 2006
- Polystyrene Data Sheet (<http://www.cctplastics.com/polystyrene.html>)
- Polystyrene and the Environment (<http://www.polystyreneps.com/environment.php>)
- Polystyrene (packaging) facts ([http://www.polystyrene.org/polystyrene\\_facts/facts.html](http://www.polystyrene.org/polystyrene_facts/facts.html))
- Polystyrene Facts ([http://www.americanchemistry.com/s\\_plastics/sec\\_pfpg.asp?cid=1421&did=5213](http://www.americanchemistry.com/s_plastics/sec_pfpg.asp?cid=1421&did=5213)) - Plastics Foodservice Packaging Group (PFPg) of the American Chemistry Council
- Polystyrene Uses and Applications (<http://www.polystyreneps.com/uses.php>)

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